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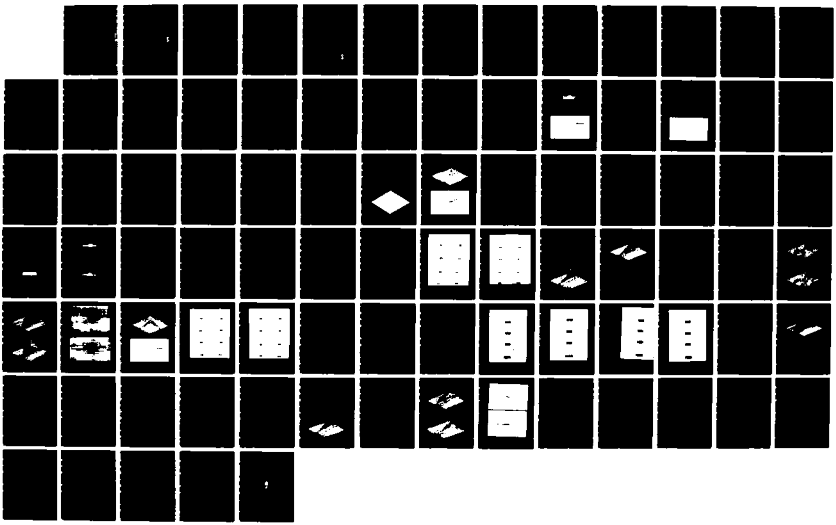

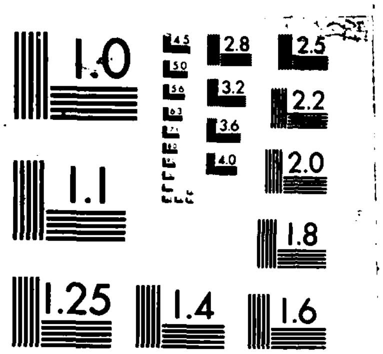

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TARGET RECOGNITION USING THREE DIMENSIONAL LASER RANGE IMAGERY

THESIS

Richard P. De Fatta
Captain, USA

AFIT/GEP/ENP/86D-2

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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This study involved the analysis of computer-generated synthetic range imagery for the purpose of autonomous target recognition. The scenario is an air-to-surface missile sensor using a laser rangefinder to image prospective targets and attempt recognition. Synthetic range images of a sophisticated Soviet T-72 tank model were created. Cross-correlation was used as a recognition technique. A reference tank image was tested against rotated images and an array of decoys. The reference image was analysed for its most prominent features for the purpose of examining feature extraction as a recognition technique. Two methods of image enhancement were compared: gradient (frequency emphasis) and phase-only filtering. It was shown that these two methods exhibited equal performance for recognition of rotated targets, but differently in decoy rejection. Phase-only filtering was more effective in the process of discriminating simple decoys from actual tanks. Feature

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19. (cont) analysis of the model tank revealed its correlation was highly dependent upon what method of image enhancement was used.

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TARGET RECOGNITION USING THREE DIMENSIONAL LASER RANGE IMAGERY

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Physics

Richard P. De Fatta, B.S., M.S.

Captain, USA

December 1986

Preface

As a Army Ordnance Officer, I was very much excited to be researching in an area of interest to my service as well as to the Air Force. This thesis ties together my undergraduate education in Weapons System Engineering, my years of experience as a Missile Materiel Management Officer, and my upcomming assignment in the Army's High Energy Laser Program. The possibility of developing an autonomous target acquisition capability in a missile seeker intrigued me, but after a year in an all Air Force environment, I appreciated the opportunity to work with a tank.

Special thanks go to Jeff Grantham. His computer program was my major analytical tool, and hours on the phone with him helped me understand it. I thank Dave King and Dan Zambon in the Electrical Engineering Department for keeping both me and the image processor on line. Also, thanks to the CSC system managers Janet and Jack for showing me the phone utility then puting up with my constant use of it for help. John Wharton, thank you for keeping me not only on the right track, but also getting me out of the depot.

I would not have finished this thesis without the loving support and understanding I have recieved from you, Michelle. You have gone way beyond the call of an Army

wife's duty. I hope you smile every time you read this, the last page of my thesis I gave you to type.

Finally, although it will be many years before you understand this, Philip, your birth and first ten months of life have been a constant source of inspiration and comfort to your thirty years young Dad.

Richard P. De Fatta

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Abstract

This study involved the analysis of computer-generated synthetic range imagery for the purpose of autonomous target recognition. The scenario is an air-to-surface missile sensor using a laser range finder to image prospective targets and attempt recognition. Synthetic range images of a sophisticated Soviet T-72 tank model were created. Cross-correlation was used as the recognition technique. A reference tank image was tested against rotated images and an array of decoys. The reference image was analysed for its most prominent features for the purpose of examining feature extraction as a recognition technique.

Two methods of image enhancement were compared: gradient (frequency emphasis) and phase-only filtering. It was shown that these two methods exhibited equal performance for recognition of rotated targets, but differently in decoy rejection. Phase-only filtering was more effective in the process of discriminating simple decoys from actual tanks. Feature analysis of the model tank revealed its correlation was highly dependent upon particular components which differed depending on what method of image enhancement was used.

TARGET RECOGNITION USING THREE DIMENSIONAL LASER RANGE IMAGERY

I. Introduction

Background

The Air Force has long been interested in the development of air-to-surface missile delivery systems which incorporate significant standoff capability. Increased standoff capability corresponds to enhanced survivability and decreased aircraft attrition rates. The closer to a target a delivery system must approach, the more effective the enemy can defense that system. Any system which incorporates significant standoff capability must possess some form of missile-borne sensor to discriminate prospective targets from background scenes and recognize prospective targets as actual high-priority targets. A missile with this capability significantly enhances the effectiveness of airborne delivery systems. This capability allows a "fire and forget" mode where no ancillary tracking system such as wire guidance is required.

In this autonomous target acquisition scenario, active target designation systems such as laser beam designators are not required. Line of sight detection on

the part of the delivery weapon system is not required. Additionally, this capability would allow the delivery weapon system to launch multiple missiles per pass within the effective range of the missile system, then depart the area of operations.

In December, 1985 the USAF Scientific Advisory Board reported that air-to-surface missile technology lagged significantly behind air-to-air and air-to-ship terminal guidance advances. It cited the diverse and rigorous demands placed on air-to-surface terminal guidance as compared to the well defined requirements and simple uncluttered backgrounds involved in both air-to-air and air-to-ship terminal guidance. (19:7)

One approach to developing a greater capability in air-to-surface missile terminal guidance is to utilize a scanning laser rangefinder to acquire and store three dimensional target scene information in a two dimensional detector array. Range-only data is largely independent of such parameters as target reflectivity and ambient atmospheric conditions. It only requires that a minimum or threshold level of radiation is returned to the detector, based on detector sensitivity. The missile seeker would capture the three dimensional geometry of the target in the form of a range image.

Objective

The Electro-Optical Terminal Guidance Branch, Advanced Seeker Division, Air Force Armament Laboratory is undergoing a research effort to develop the sensor technology to recognize potential targets via laser range imagery. A previous student, Jeffrey W. Grantham, GEP 85-D, developed a computer program which accurately simulates the range information that would be received by a laser range sensor scanning simple geometric shapes. He used the program to model the laser range image of an extremely simple model of a Russian T-72 tank. The program also performs correlations between reference images and "scanned" objects.

The overall objective of this research was to further explore the feasibility of utilizing a laser range sensor for object recognition in air-to-surface missile seekers. Specifically, the object recognition technique of image correlation was to be further examined. A sophisticated model of a Russian T-72 tank was developed to be used as the primary reference object. The ability of the cross-correlation technique to discriminate the target under the conditions of rotation and scale variance was examined. Additionally, analysis was made to ascertain this method's susceptibility to decoys and the level of sophistication required in a decoy to fool the sensor.

II. Theory

Range Imagery

Operation of a range-only sensor for aquisition and recognition of potential targets encompasses three separate processes: detection, enhancement (image processing), and recognition. Detection includes the mechanical, optical, and digital processes inherent in gathering the raw data describing the range scene. This is the physical portion of the sensor, including the detector array, a laser scanning mechanism and associated optics. The critical parameter is the threshold sensitivity of the detector. To form a laser range image, it is only necessary that sufficient energy return is received by the detector to exceed its threshold detection limit. The information required is simply the time it takes for the laser pulse to travel from the missile to the target and back.

Image enhancement includes any preprocessing that is done to the range image prior to its use in the recognition function. This includes such techniques as repairing images degraded due to weak energy return, which result in pixel dropouts. An averaging technique used on adjacent pixels yields a complete, correlatable image. Enhancement techniques are also used to highlight the shape information present in the edge map of an image

while suppressing area information.

The final process is recognition: once detected, an image must be recognized as a target or rejected. The method investigated in this research is image correlation. In general, the target is scanned, and the resulting range image is compared with a reference scene or filter stored either optically or digitally in the missile. If the image "looks" sufficiently like the reference scene, then it is identified as a target. The following three sections describe in some detail the three processes summarized above.

Image Detection

A laser range sensor's basic function is to compute the distance from the sensor to the nearest scene point along a given ray. Each pixel in the detector array records the range value for its position in a raster of ray displacements. In this manner the sensor produces the three dimensional information (scene geometry). Lengths, areas, and location can therefore be derived. This method of object detection is ideal for manmade objects such as buildings or vehicles as these tend toward large areas of planar surfaces and angular displacements.

There are several assumptions necessary in this analysis. A basic objective of a terminal homing system is to determine the location of the target relative to the

sensor. Angular orientation of the target is a key parameter. The flight heading of the missile sensor must also be known. In this simulation a constant missile heading, missile height above terrain, and sensor declination angle is assumed. Additionally, the terrain is assumed to be level, and the missile's speed constant. A paraxial approximation is used to simplify the scenario (9:7). Given the distance to the target (approx 1 km) compared to the target dimensions (approx <10m), this assumption is valid. A complete mathematical development and description of the scanning geometry is available in Grantham's thesis (9:8-13). In order to provide a valid basis for comparison this research will utilize the same initial parameters dominant in Grantham's work; missile height of 300 meters and a sensor depression angle of 20 degrees. This places the laser scan at 0.82 kilometers in front of the missile, with a slant range of 0.88 kilometers.

The range image is formed on a 256 x 256 detector array. The simulated raster scans horizontally by varying the x coordinate, and moves forward by varying the z coordinate. The result is a two-dimensional array which includes a third parameter, the range to that point (9:10). All array values are based on a set value of zero for the ground or zero level. The special capability of laser range imagery is that the x,y and z location of

pixels on an object can be used to determine length, width, height and therefore, area and volume of an object independent of object orientation, attitude, and to some extent, altitude (1:48).

The accuracy of the range data is dependent on the parameters of the system (transmitted beam power and detector variables) and on target characteristics (orientation and reflectance of target surfaces, and actual distances from the sensor.) System parameters and target characteristics affect the strength of the signal returning to the sensor and therefore affect accuracy (16:174).

Image Processing

Once the raw range image data has been captured in the detector array it must be compared with a stored reference scene for a potential target to be recognized or rejected. It is desirable to pre-process the image in any manner which would facilitate the comparison, known as image processing. An image is processed digitally or optically to optimize the object signal for recognition. Image processing techniques are used to enhance the electronic image for human or computer viewing (5:2).

The unprocessed range image contains both area and shape information. It is the shape information that is most important as this defines the object boundaries in

space. Grantham (9:44-51) demonstrated how two quite different objects, a cylinder and a rectangular box of similar exterior dimensions correlate very close to each other when both area and shape information is included in the comparison. If the area information is removed, the shape is retained and only edges appear. This is called edge enhancement. Figure 1 is a synthetic range image of a Soviet model T-72 tank. Figure 2 is the edge enhanced version of the same tank image. Notice that the edge enhanced version, though devoid of area information, is as recognizable as the full image. The area information is extraneous "noise" not required for object identification. There are a variety of ways to edge enhance an image. Two methods were utilized in this research: gradient filtering, and phase-only filtering.

The magnitude of the gradient of a function is the magnitude of the greatest change in the function at the point where the gradient is taken (9:54). Therefore, gradient filtering an image emphasizes all points where the intensity changes, and sets equal to zero all those points where there are no intensity changes. The effect on a range image is to enhance the edges and eliminate most of the area information.

Edge enhancement is accomplished through optical filtering, a form of optical processing in which the spatial Fourier Transform of an object is operated on in

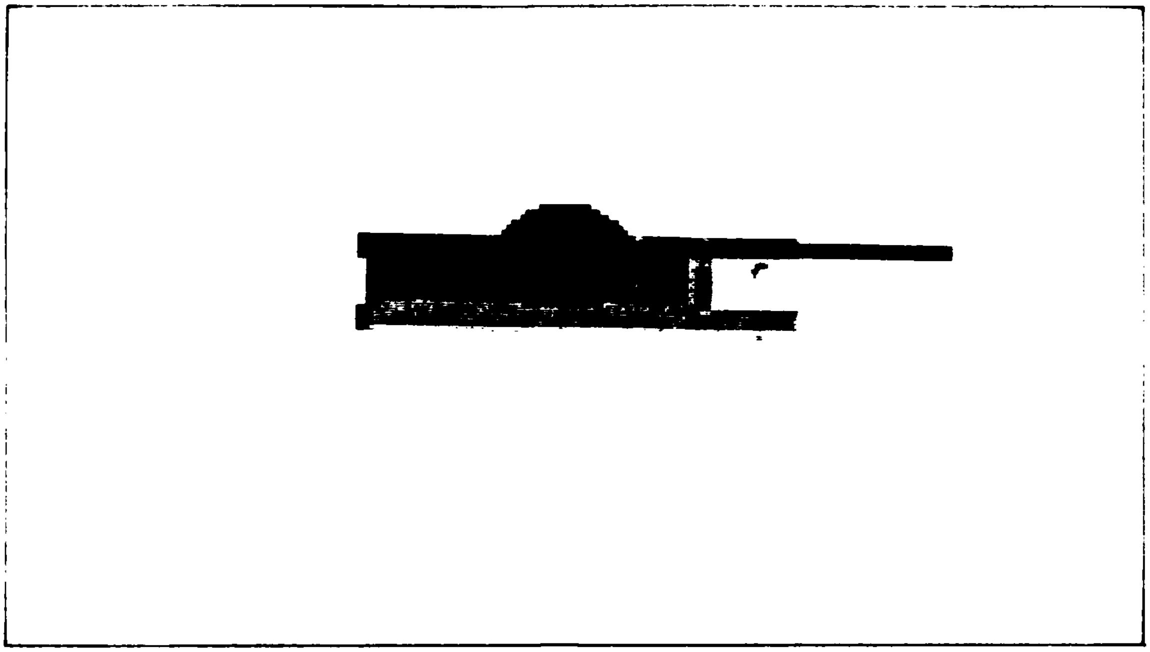

Figure 1. Synthetic Range Image of a Model Soviet T-72 Tank

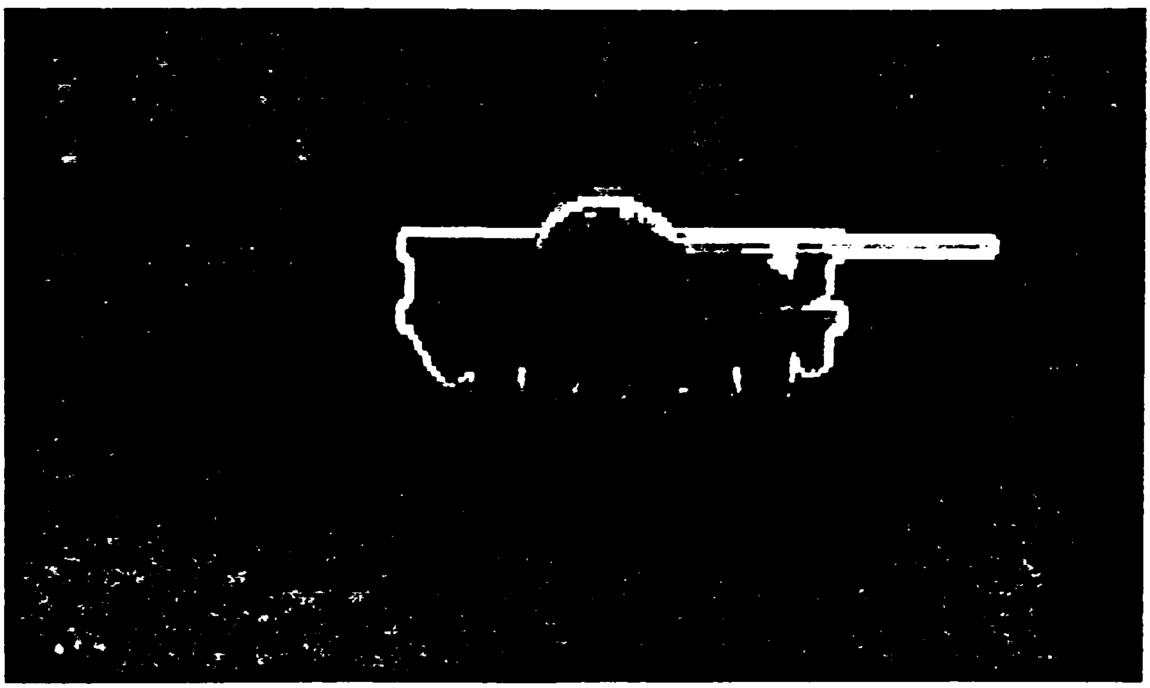

Figure 2. Edge Enhanced Range Image of a Model Soviet T-72 Tank

such a way as to have a predetermined effect on the image (20:107). The Fourier Transform of an object contains all the information in the original image but it is arranged according to spatial frequency instead of spatial location. "Noise" or extraneous information such as the area information in a range image may overlap with critical information in the image domain but exist separately in the frequency domain. Small details in an image are made up of high frequencies. Large continuous areas are primarily low frequency. The process, therefore, is to Fourier Transform the image to frequency space, filter out the low frequencies then take the inverse Fourier Transform to image space with the noise removed. The filter can be high, low or band-pass. If a high pass filter is used, edges are detailed and areas removed. If a low pass filter is used, images blur. A band-pass filter is designed for applications where the specific frequencies that contribute to the image can be precisely determined.

This type of frequency emphasis can be accomplished both optically and digitally. For the purpose of this research it was implemented digitally by taking the Fourier Transform and multiplying each frequency component by its own frequency (9:55). Frequency emphasis filtering, therefore, involves multiplying the image transform by a filter function which acts to attenuate or

emphasize desired frequencies. It adjusts the spectral magnitude of the image (9:59).

As its name implies, phase-only filtering involves reducing the Fourier Transform of an image to its magnitude and phase components and effectively eliminating the magnitude, leaving the phase. This is achieved by setting the magnitude of each frequency component equal to one and implemented by dividing each pixel magnitude by itself. It has been shown (17:529) that when the image Fourier Transform magnitude is set to a constant, without changing the phase, and the inverse Fourier Transform is taken, the resulting image closely resembles the original. In contrast, image features are not discernible in a magnitude only image. Figure 3 is the same input image as

Figure 3. Edge Enhanced Range Image of a Model Soviet T-72 Tank (Phase-Only Filtered)

Figure 1 and Figure 2, enhanced using a phase-only filter. Notice the similarity with the frequency emphasized edge enhanced version (Figure 2). Phase-only filtering is very much similar to a high-pass filter. It has high frequency emphasis which emphasizes edges. Butler (5:59-60) explains that the spectral magnitude of most images tends to fall off with frequency. Since the magnitude is set to one by multiplying each individual pixel magnitude by its reciprocal, the higher frequencies tend to be emphasized.

A third enhancement technique exists called complex or holographic filters. This type of filter is detailed by Butler (5:62-67) and Steward (20:112-114) but is beyond the scope of this research.

A final aspect of image processing to be discussed is that of repairing degraded range images. Pixel dropouts occur at the detector array due to poor laser radiation return. If insufficient energy reaches the detector to trigger its threshold detection level, the pixel is set to zero. Conversely, if the return is too strong to be valid, the pixel is again set to zero. The resultant image is in either case severely degraded. Grantham (9:33-34, 115-120) found that a dropout rate of only 2% caused severe enough degradation for the image to be rejected as a valid target. He developed a median replacement method of pixel averaging to repair the

degraded images prior to edge enhancement. This method of repair proved completely successful in returning an acceptable image even at dropout rates of up to 40%.

Object Recognition

Once a potential target has been detected, imaged, and the image pre-processed, the process of recognition begins. The method used to identify the object actually drives the form of pre-processing of the initial image. Research into object recognition has gone in many directions. Recent advances in laser range imagery have stimulated this research. The unique nature of a range image is its ability to capture the three-dimensional geometric shape of a scanned object in a two dimensional array. Image processing and object recognition tasks are potentially achieveable through optical or digital methods, and ultimately through a combination of the two methods. The most widely used means of identifying objects is known as cross-correlation. Simply stated, a cross-correlation is a means of comparing one image with another. Mathematically, a two dimensional cross-correlation function c(x,y) is defined as (20:79):

$$c(x,y)=f(x,y)*g(x,y)=\iint_{-\infty}^{\infty} f(x',y')g(x'-x,y'-y)dx'dy' \quad (1)$$

Here "*" indicates a correlation and x' and y' are dummy

variables of integration. The correlation can be visualized as shifting the function g with respect to f by x, y and determining the area of overlap (Figure 4).

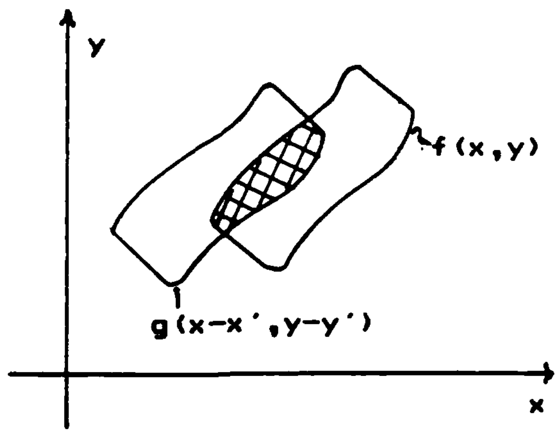

Figure 4. Cross-Correlation Image

In the specific case of range images g(x,y) represents the scene image and f(x,y) represents the stored reference scene. Gaskill (6:172-3) shows that the cross-correlation operation is not commutative. It is, therefore, necessary to pay particular attention to the order in which the functions are written and which function is conjugated. Similarly, if f(x,y) and g(x,y) are identical functions, the correlation operation is called an auto-correlation and is defined as:

$$a(x,y)=F(x,y)*f(x,y)=\iint_{-\infty}^{\infty} f(x',y')f(x'-x,y'-y)\,dx'dy' \quad (2)$$

Correlation of a range scene with a reference scene involves both the cross-correlation and auto-correlation operation. If the two scenes are very similar, the correlation will result in a very high central peak value of nearly 1 (if normalized). If the two scenes are dissimilar, then the peak value will be degraded in accordance with the degree of dissimilarity. This central peak value can be described as a useful measure of the "goodness of fit" of the range image with the reference scene. In order for the comparison to be valid, the cross-correlation must be compared with the auto-correlation of the reference scene. This is implemented by dividing the max value of the auto-correlation into the cross-correlation to obtain a correlation coefficient. A perfect match would be a one. Any dissimilarity in the images results in a correlation coefficient less than one. The correlation coefficient will be utilized in this research as the parameter to compare the various correlations.

One advantage of the correlation technique is that it is readily implemented both optically and digitally. Figure 5 is a simplified diagram of an optical correlation technique (21:302) where $f(x,y)$ and $g(x,y)$ are transparencies. If the $g(x,y)$ transparency is displaced by x_d, y_d relative to the image at $f(x,y)$ then the photo multiplier measures:

$$f(x,y)g(x+x_0,y+y_0)dxdy. \qquad (3)$$

In order to determine the cross-correlation function, f(x,y) and g(x,y) must be aligned in all possible relative positions in turn. This is mechanically difficult and impractical. If the point source of Figure 5 is replaced

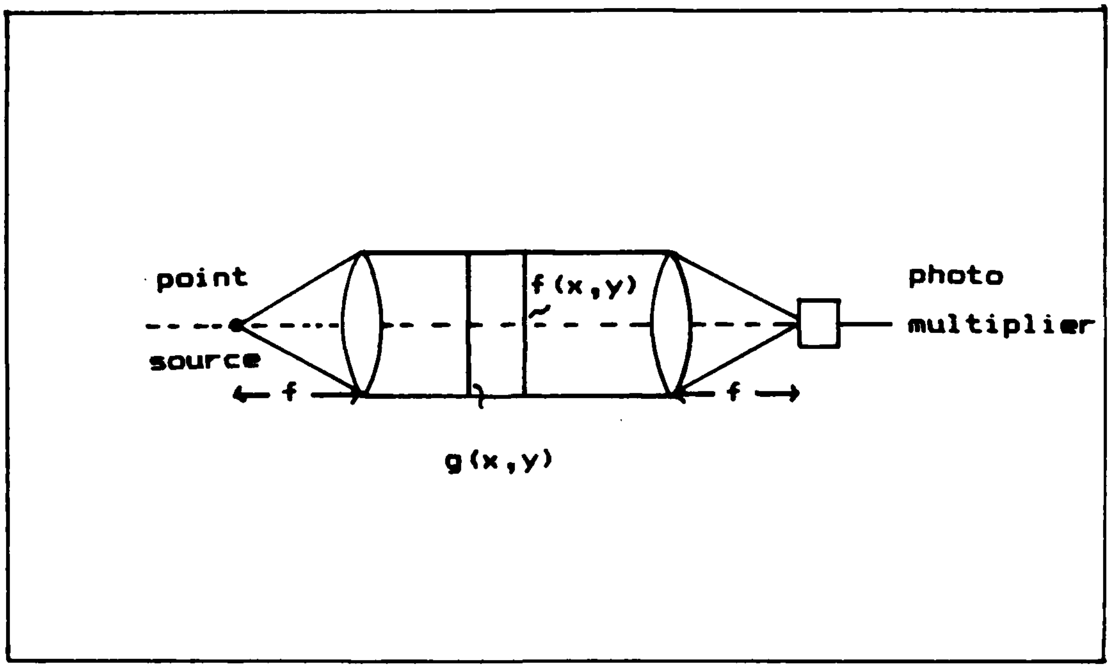

Figure 5. Optical Correlation System

by an extended source, the cross-correlation can be obtained instantaneously. Using holographic techniques, a cross-correlation can also be obtained instantaneously (21:301-302). Optical correlations, therefore, utilize matched filtering. The filter transparency of Figure 5 is matched to the input signal. Figure 6 is a schematic of

an optical system used for instantaneous correlations (8:179):

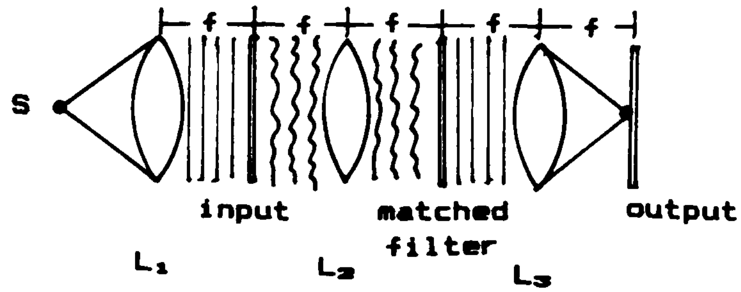

Figure 6. Optical System for Instantaneous Correlations

The presence of the signal for which the matched filter is produced can be discovered by measuring the output intensity of light at the focal point of the final lens.

In this research correlation is achieved digitally. The basic operation performed in a correlation is a two-dimensional Fourier Transform. Optically, the Fourier Transform is achieved by sending the input through a converging lens in a coherent optical system (8:83-90). The Fourier Transform is digitally performed using a computer algorithm known as a Fast Fourier Transform (FFT). The FFT performs a discrete Fourier Transform (9:42). The digital correlation is achieved by

implementing the correlation theorem (3:66-68):

$$z(x,y)=FT^{-1}[G(f_x,f_y)F^*(f_x,f_y)]. \qquad (4)$$

$G(f^x,f_y)$ and $F(f_x,f_x)$ are the Fourier Transforms of $g(x,y)$ and $f(x,y)$, "*" represents the complex conjugate, and FT^{-1} implies the inverse Fourier Transform. Performed discretely, the continuous Fourier Transforms are replaced by discrete Fourier Transforms. The functions are replaced by matrices which contain discrete points of the functions. A digital correlation is performed by taking the FFT of the input and reference arrays, multiplying the resulting arrays element by element, then inverse FFT the result (9:43).

Coherent optical correlators have been used in several applications (5:68). Since the Fourier Transform is invariant to translation shift in two dimensions, an optical correlator could scan a large scene for a specific pattern, and correlation could occur anywhere in the image. Correlations do have the major disadvantage that they are extremely sensitive to the changes in the input scene such as rotation, scale changes, and geometrical distortion. In the real life scenario of trying to recognize a potential target the major problem to be overcome is object rotation. Scale invariance would actually help to reject, for example, a scaled-down model

decoy placed in a scene to fool the sensor. Geometrical distortion is compensated for by distorting the reference image in a similar manner. If the sensor scans at a preset depression angle and height above the ground, the geometrical distortion can be predicted and incorporated into production of the reference image. There are transformations other than the Fourier Transform that provide scale and rotation invariance. Butler (5:69-70) notes and describes the Mellin and Fourier-Mellin transforms as examples of such tranformations.

For the purpose of this research, correlations are performed digitally in accordance with the discrete version of equation 4. Reference images are auto-correlated to provide a reference for the cross-correlation of an input scene with the reference. The value of the cross-correlation central peak is divided by the reference auto-correlation central peak to establish a correlation coefficient. The correlation coefficient is used to provide a measure by which to compare how well various perturbed scenes match the reference scene.

Figure 7 is an example auto-correlation of a tank rotated 45 degrees, centered in a 256x256 pixel array. Notice the spiked central peak. This has a magnitude of one and shows, as expected, that this image correlates well with itself. Figure 8 is the same auto-correlation.

In this figure, only the central 50x50 pixels of the array are displayed. The relative magnitude of the central peak appears to have changed, but in reality the normalization procedure in the plotting routine has caused the change. The central 50x50 pixel display is used because it contains the bulk of the information useful in the analysis of a particular correlation. Figure 9 is a tops down projection of the correlation and is used to present more clearly the overall shape of the correlation.

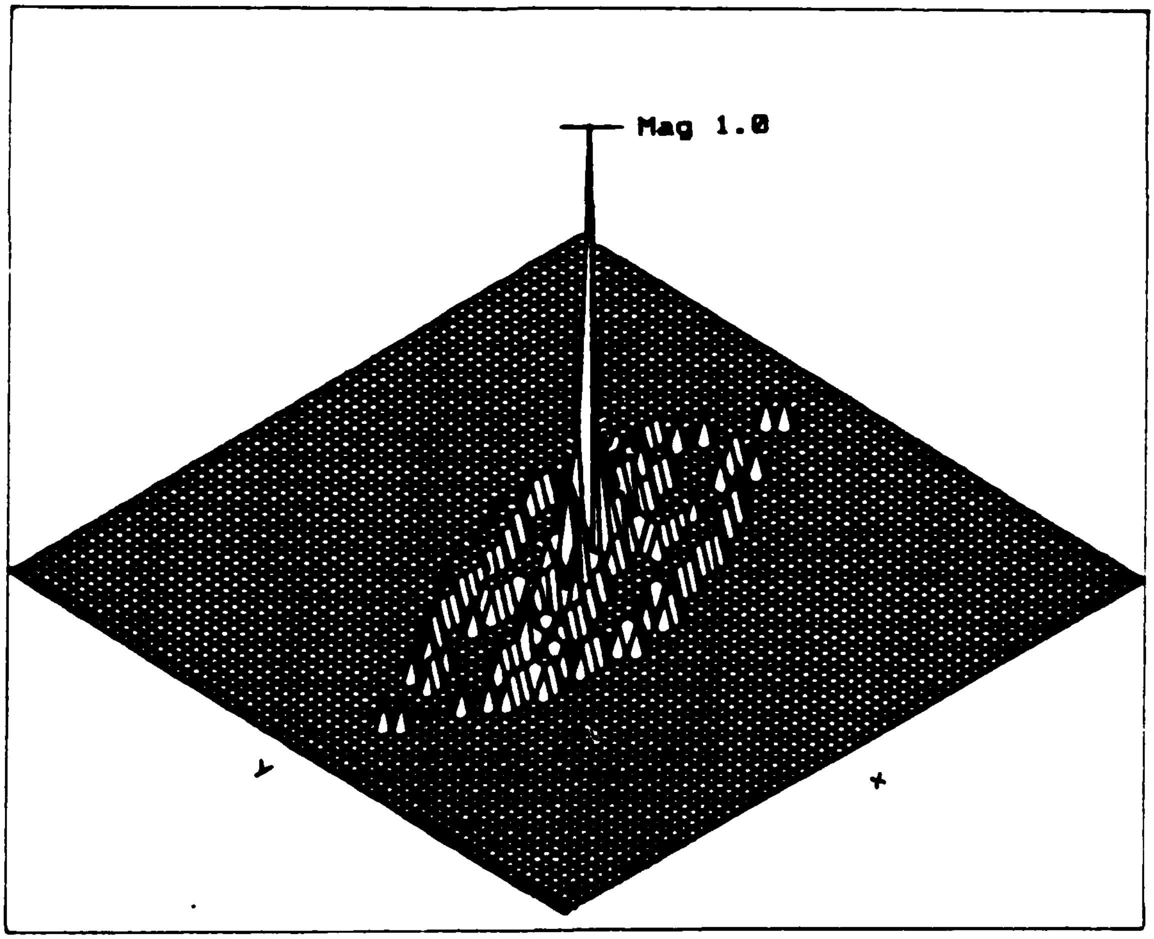

Figure 7. Auto-Correlation of a Soviet T-72 Tank Rotated 45 Degrees (256x256)

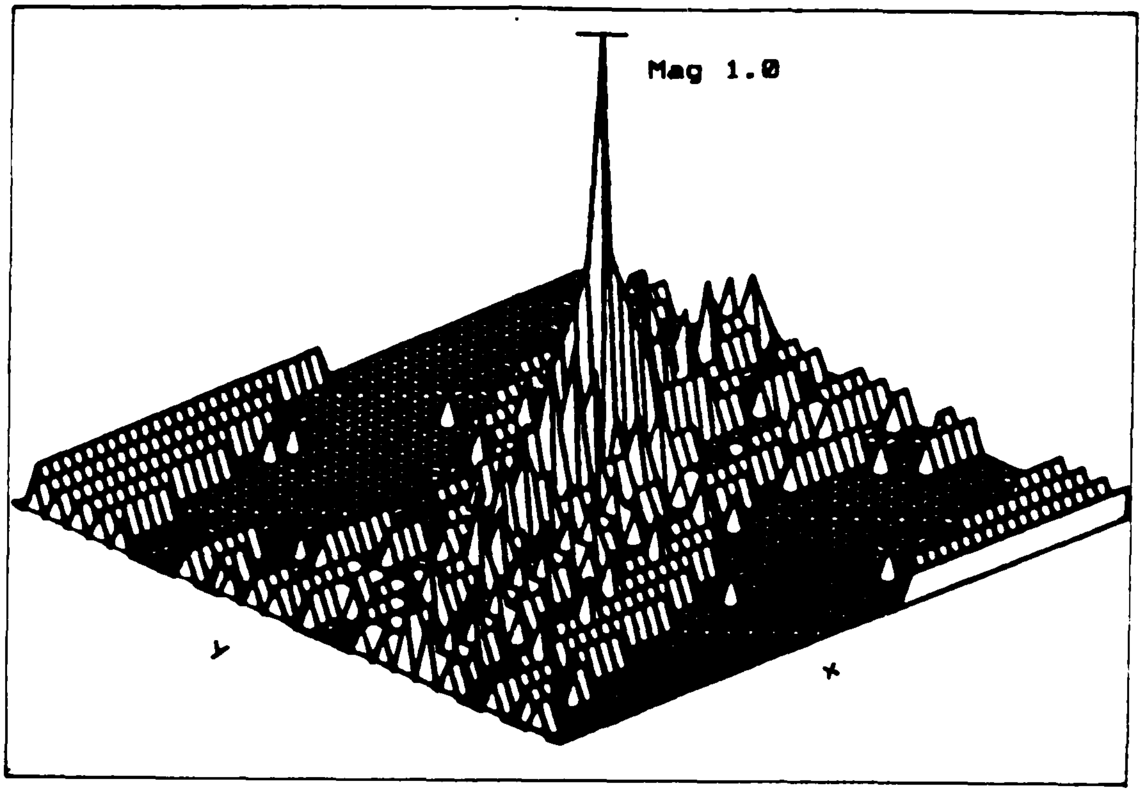

Figure 8. Auto-Correlation of a Soviet T-72 Tank Rotated 45 Degrees (50x50)

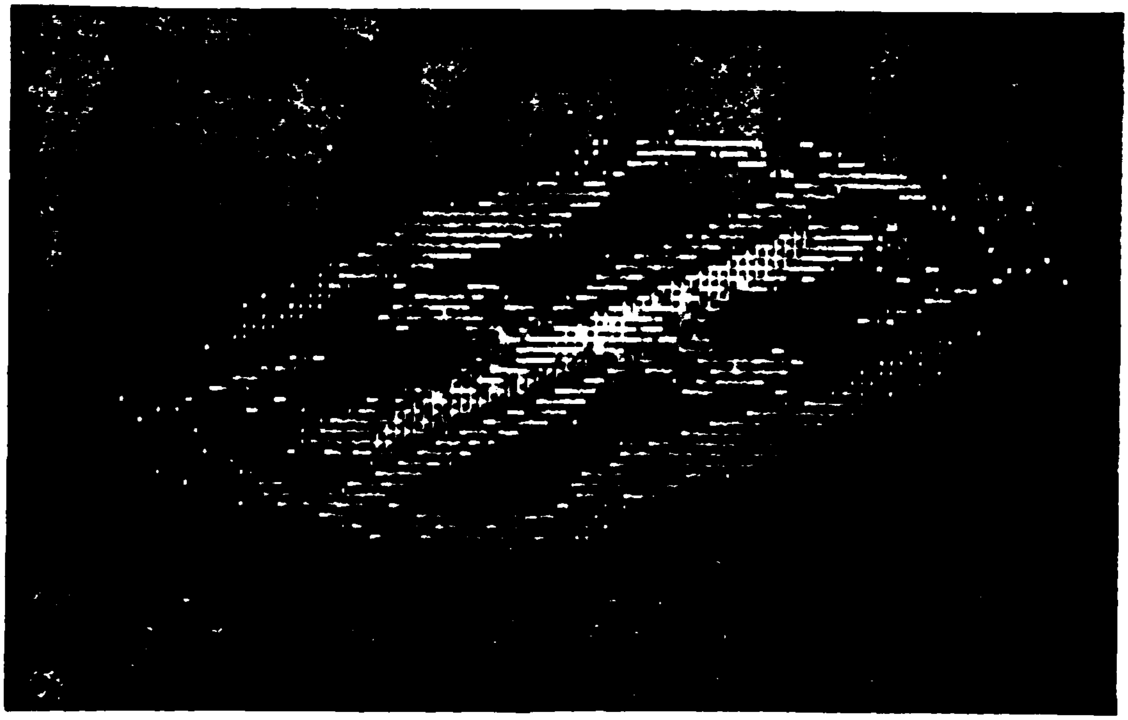

Figure 9. Auto-Correlation of a Soviet T-72 Tank Rotated 45 Degrees (Tops Down)

III. Research Methodology

Various researchers have approached the area of pattern/object recognition from many directions. This research effort is designed to compliment some of those methods. In particular, Grantham (9) investigated correlation methods using synthetic data simulating actual range imagery. He compared a reference image with various input images in an attempt to identify and locate a particular image. An end product of his research was a computer program that formed simulated range images by modeling the scanning of an actual laser range detector. The program also included a correlation routine to compare two range images.

Grantham utilized a very simple tank model consisting of several rectangular boxes and a cylinder with the overall dimensions of a Russian T-72 tank. With this simple model basic attributes of laser range imagery and object correlation were demonstrated: the three dimensional nature of laser range images and correlation weaknesses such as rotation and scale invariance.

A major goal in this research was to create a sophisticated model and move closer to the real world scenario in which the proposed laser range imaging air-to-surface missile seeker would operate. This included a look at its vulnerability to decoys and the

level of sophistication required in a decoy to fool the sensor. It also involved a look at what object characteristics tend to dominate the correlation. This is important because it ties in with other researchers (detailed later) that are looking at extracting features from a given object for recognition as opposed to full object recognition.

Resources utilized in the conduct of this research amounted to a Digital Equipment Corporation 11/785 VAX, and an Eclipse Digital Image Processor. Software changes were held to a minimum. The major modification to the existing program was additional code to implement the phase-only image filtering process.

Object Modeling Process

The primary object imaged in this research was the Soviet T-72 main battle tank. This provided continuity with previous research and a ready comparison with the real world scenario. A schematic of the tank is included as Figure 10. In preparing the model for input to the computer for imaging, it was important that all major features of the tank in their proper location and proportion be included. Minute details were unnecessary. Due to the expected laser spot size on target of 10 to 20 centimeters, small details would not show up in the range image (9:25-28). The features that are most important in

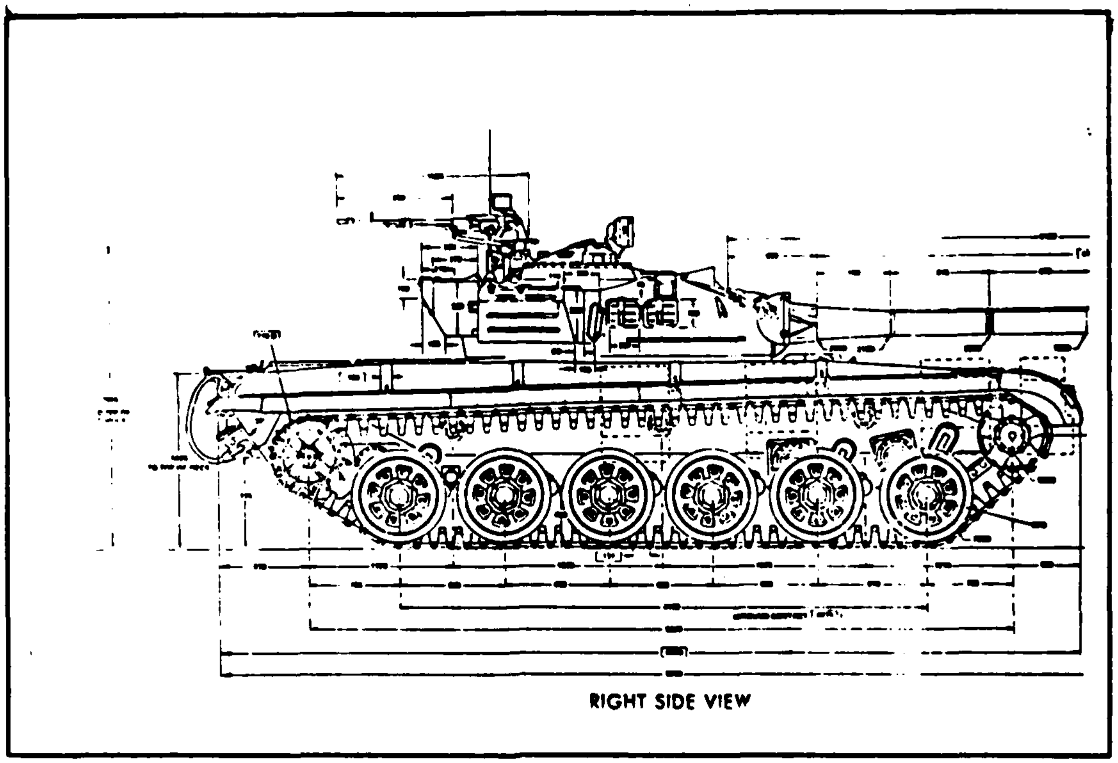

Figure 10. Soviet T-72 Tank Schematic (Courtesy U.S. Army Foreign Science and Technology Center)

the correlation process are the edges. Therefore, any significant edge source within the image must be included. The T-72 tank's main edge sources are its hull outline, the gun tube, the side skirts/tread covers, and the turret. The hull incorporates slanting surfaces at both ends. The forward surfaces are most significant as they contribute a major edge outline to the image.

Modeling the slanting surfaces proved to be the most difficult. The computer program allows the use of spheres, rectangular boxes, and cylinders. These surfaces were modeled using progressively smaller cylinders. Figure 11 is a schematic diagram of the model. The

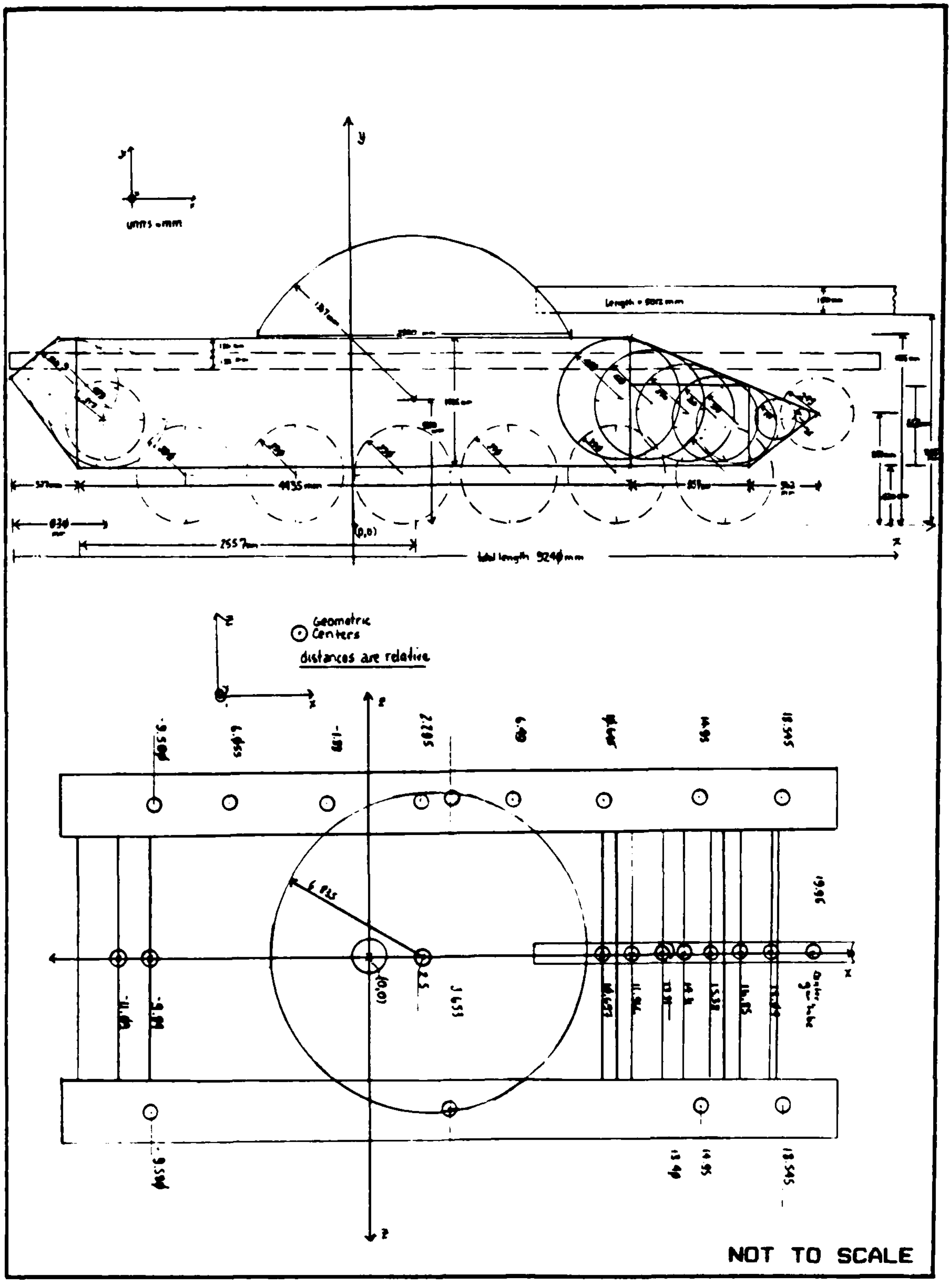

Figure 11. Soviet T-72 Tank Model

cylindrical rendering of the slanted surfaces could not produce a perfectly flat area, but the surfaces were adequate within the "granularity" of the imaging process. A better surface could have been produced simply by decreasing the incremental size of the cylinders composing the surface. The benefit was questionable since each additional component of the model increased the run time of the program, which scans each input object individually. The model utilized 26 separate components and required approximately 45 minutes of actual time to produce an image. Since the correlation process depends heavily on edges, any improvement in the edge makeup of the image would improve image correlation. However, in this research increasing the number of cylinders did not notably affect the correlations and the simpler version was used.

The turret on a T-72 is not of regular geometric proportions. With the given limitations in modeling tools, the "best fit" model turret was achieved by imbedding a sphere within the hull block.

Figure 1 is the actual image of the model T-72 taken from the image processor screen. To improve the tank's realistic image quality, road wheels were included at all locations on the tank not obscured by the tank hull. As will be shown in the next chapter, their presence proved to be mostly cosmetic. Deleting the

wheels had very little effect on the correlation magnitudes. From here on the full-up model T-72 will be referred to as the "reference tank". All images, otherwise unless noted are taken at a missile height of 300m and sensor depression angle of 20 degrees.

<u>Decoy Modeling</u>

Three primary decoys were utilized for comparison and correlation with the reference tank. The first was a simple rectangular block with the same overall dimensions of the reference tank hull. While it is not realistic as a viable decoy, this simple decoy was included because it proved extremely effective against the simple model used by Grantham in his research. This was reasonable because his model closely resembled the block decoys (9:69). Decoy 1 is useful for comparison with previous research, and is depicted in Figure 12.

Decoy 2 was created to examine the effect of the turret shape on the correlation. It consists of decoy 1 with the turret from the reference tank (Figure 13). Examining an edge enhanced version of the reference tank in both its frequency-enhanced form and phase-only form reveals what appears to be a significant amount of energy concentrated in the turret outline. It was, therefore, tested to reveal the reliance of the correlation on the turret shape.

Decoy 3 was created from decoy 2 with the addition of a gun tube similar in length and radius to the reference tank gun tube (Figure 14). Grantham (9:71) concluded that the gun tube was a distinguishing characteristic of the tank. Decoy 3 was designed to test this conclusion, and to be the most realistic decoy.

In addition to the three primary decoys, the reference tank was tested against a variety of other objects proposed as decoys against this type of imagery such as cylinders mimicking the size and shape of the gun tube.

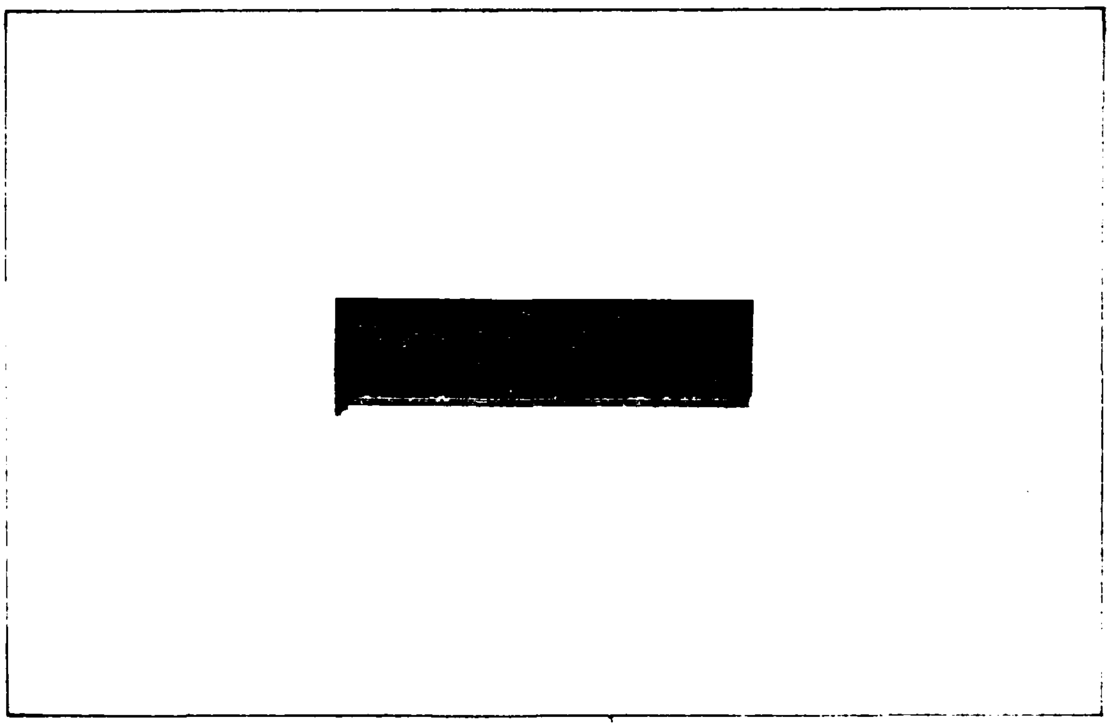

Figure 12. Range Image of Decoy 1

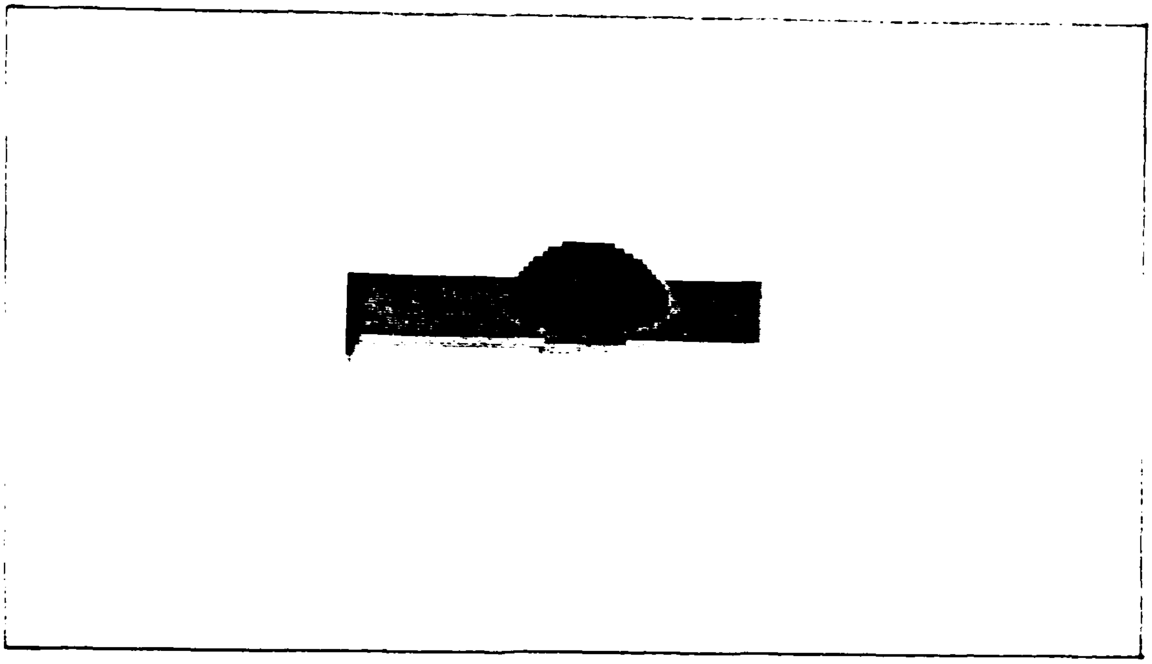

Figure 13. Range Image of Decoy 2

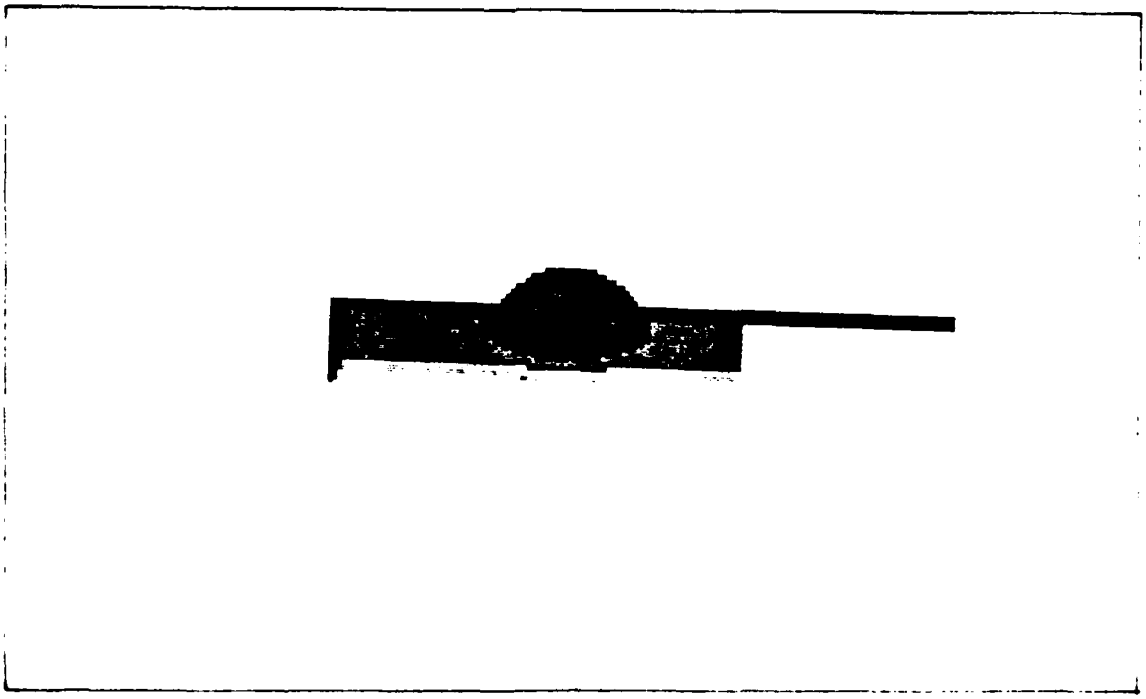

Figure 14. Range Image of Decoy 3

Scaling

In order to provide an image large enough for a detailed view on the image processor, the input objects were scaled so that they filled a large part of the simulated detector array without exceeding the array boundaries. Since the program simulates a 256x256 meter area, inputing the approximate 7 meter tank hull without scaling the dimensions utilizes only a small portion of the detector array area. Therefore, the input images were scaled such that the resulting spot size on the object being scanned was 8.1 cm. This is derived from 8.1 cm increments in the x and y direction and 22.25 cm in the z direction (given a 20 degree sensor depression angle.) The 22.25 cm increment in the z direction corresponds to the slant range elongation of the beam, a divided factor of the tangent of the depression angle (9:16). The incremental dimensions translate into the reference tank being sampled 85 times in the x direction (length). The resulting image of the reference tank is very well defined (Figure 1). The various gray levels which appear as contours in the image represent the difference in range from one scan to the next; darker areas are closest, light areas indicate progressively farther away areas. These contours serve to define the slope and relative angles of the surfaces on the object. In areas where there is no relief and the ground is flat, the image appears blank.

IV. Results and Discussion

An unstated but none-the-less underlying objective of this study was to attempt the identification of a threshold correlation maximum or correlation coefficient which could be used to identify a specific object. This is extremely difficult because there is a multitude of variable parameters, including the object itself, the missile trajectory parameters, and degree of sensor sophistication. A correlation coefficient for one object would not particularly apply to another. An infinite number of iterations are possible; these results represent only a sample utilizing a best guess scenario and input parameter selection.

Results are presented from four data collection sets. The primary set utilized a beam spot size of 16.2 cm and frequency emphasized pre-processing (edge enhancement). This spot size data is nearest to actual data taken at Eglin Air Force Base. The effect of spot size was demonstrated by Grantham (9:106-114), where an optimum spot size served to enhance the most prominent features without eliminating them. The 16.2 cm spot size data was obtained by using a median process to average the pixel values of four adjacent pixels in the 8.1 cm scan and replace that value back into those same four pixels. This effectively doubles the nominal spot size on target.

For comparison some of the data was repeated at the nominal spot size of 8.1 cm. This provided sharper, more distinct images. The third and fourth sets of results presented are those obtained using the phase-only filtering process for image enhancement, at both the 8.1 and 16.2 cm spotsizes.

Rotation Analysis

One of the most important pieces of information is an object's orientation in a range scene. Using correlation for object recognition requires the two dimensional Fourier Transform which is not rotationally invariant (discussed in Chapter II). Kuan (10:1-2) discusses obtaining an object's orientation utilizing its ground projection. This information (orientation) is not directly available from the range data.

The cross correlation has been shown to be highly vulnerable to rotation of the input image. This research does not refute that conclusion. The reference tank was rotated through orientations in the first quadrant (0-90 degrees) and the resultant image cross correlated with the reference tank at zero degrees. Figure 15 is a graph of those results using frequency emphasis for enhancement. The line in the second quadrant represents an estimate of the actual values, terminating in an actual experimental value at 180 degrees of rotation. It is expected that

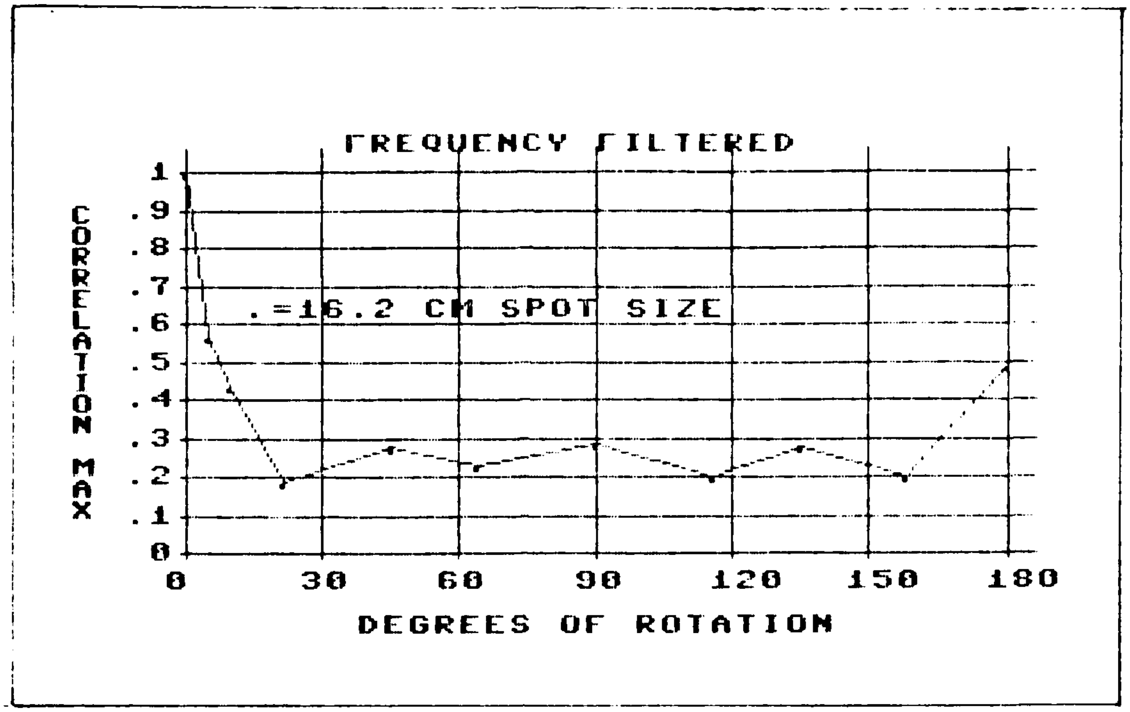

Figure 15. Correlation Maximums of Rotated T-72 Tank with Reference Tank (Frequency Filtered at 16.2 cm Spot Size)

values in the second quadrant would approximately mirror those in the first. Grantham (9:86) reported a stronger correlation at the 90 and 180 degree rotations. This is understandable, given the highly symmetric nature of his reference tank. The simple tank lost its correlatable identity at only 1 degree of rotation. The data presented in Figure 15 indicates a reasonably high correlation up to approximately four degrees of rotation. This agrees with results reported by Leger (11:274), but unfortunately, four degrees of freedom (eight if both directions are considered) is not a great deal of real world latitude.

If this eight degree range held for any reference orientation, it would require correlation with 45 separate reference filters to insure a particular orientation is recognized as a tank.

One would expect a relatively smooth curve for the rotation. However, Figure 15 appears to show an anomally at the 22 degree data point. Figure 16 shows the multiple orientation images in an edge enhanced form. Notice the jagged nature of the gun tube image in the 22 degree rotation. This is due to the averaging process reducing the smooth nature of the gun tube. Since the gun tube appears to have a major impact on the correlation due to its prominence, deviations severely degrade the results. Figure 17 shows the same multiple orientations scanned with an 8.1 cm spot size. The resulting images illustrate a smoother outline since the tank is sampled twice as many times by the smaller beam.

Figure 18 plots the results of the rotated correlations using the smaller spot size. Since this smaller spot size provides finer detail and does not enhance the prominent features through enlargement, the correlation drops off more rapidly and farther. This is illustrated by examining the correlation plots associated with particular rotations. Figures 19 and 20 are the auto correlation plots for the reference tank with spot sizes of 16.2 cm and 8.1 cm respectively. The 8.1 cm

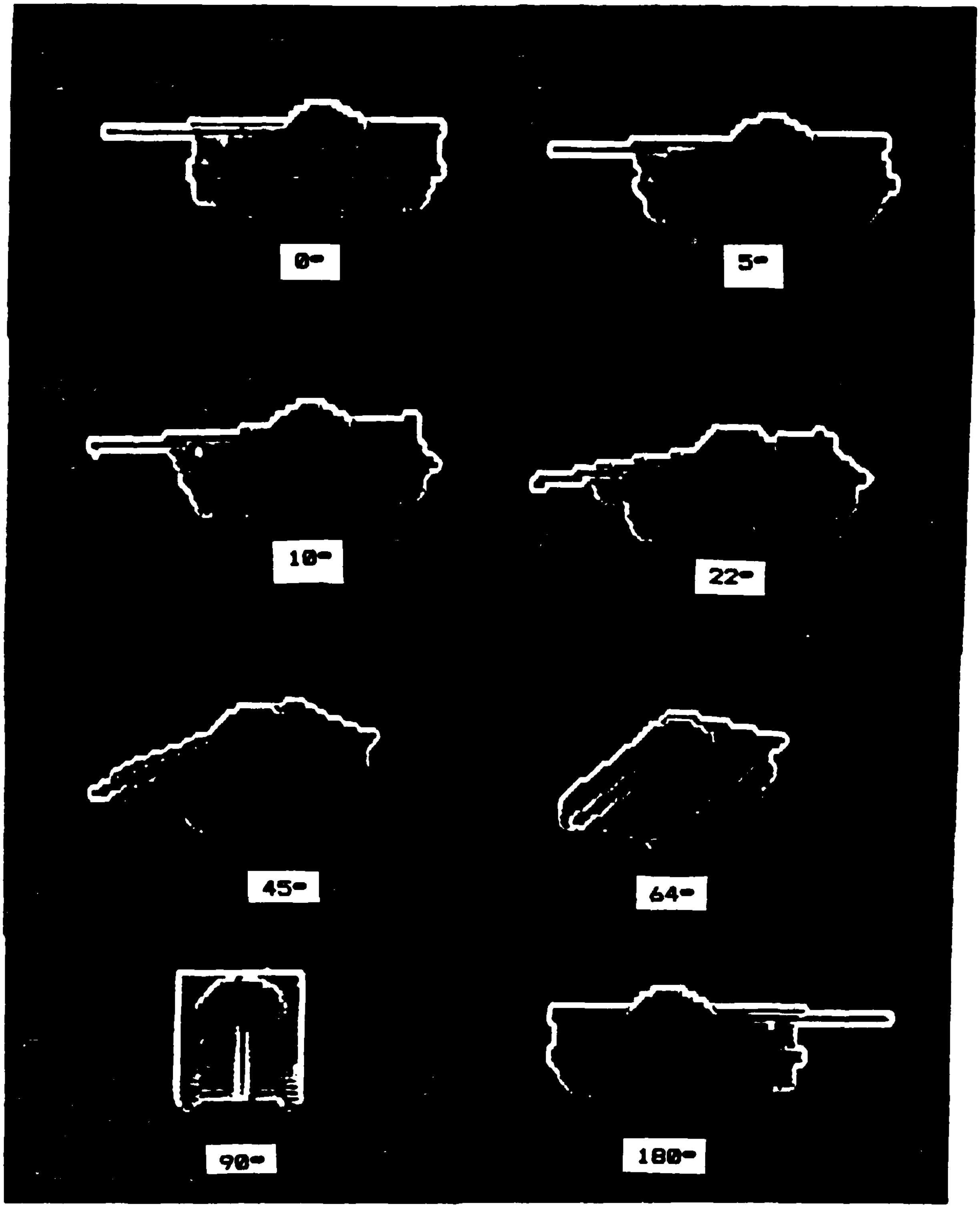

Figure 16. Edge Enhanced Range Images of Rotated Reference Tank (16.2 cm Spot Size)

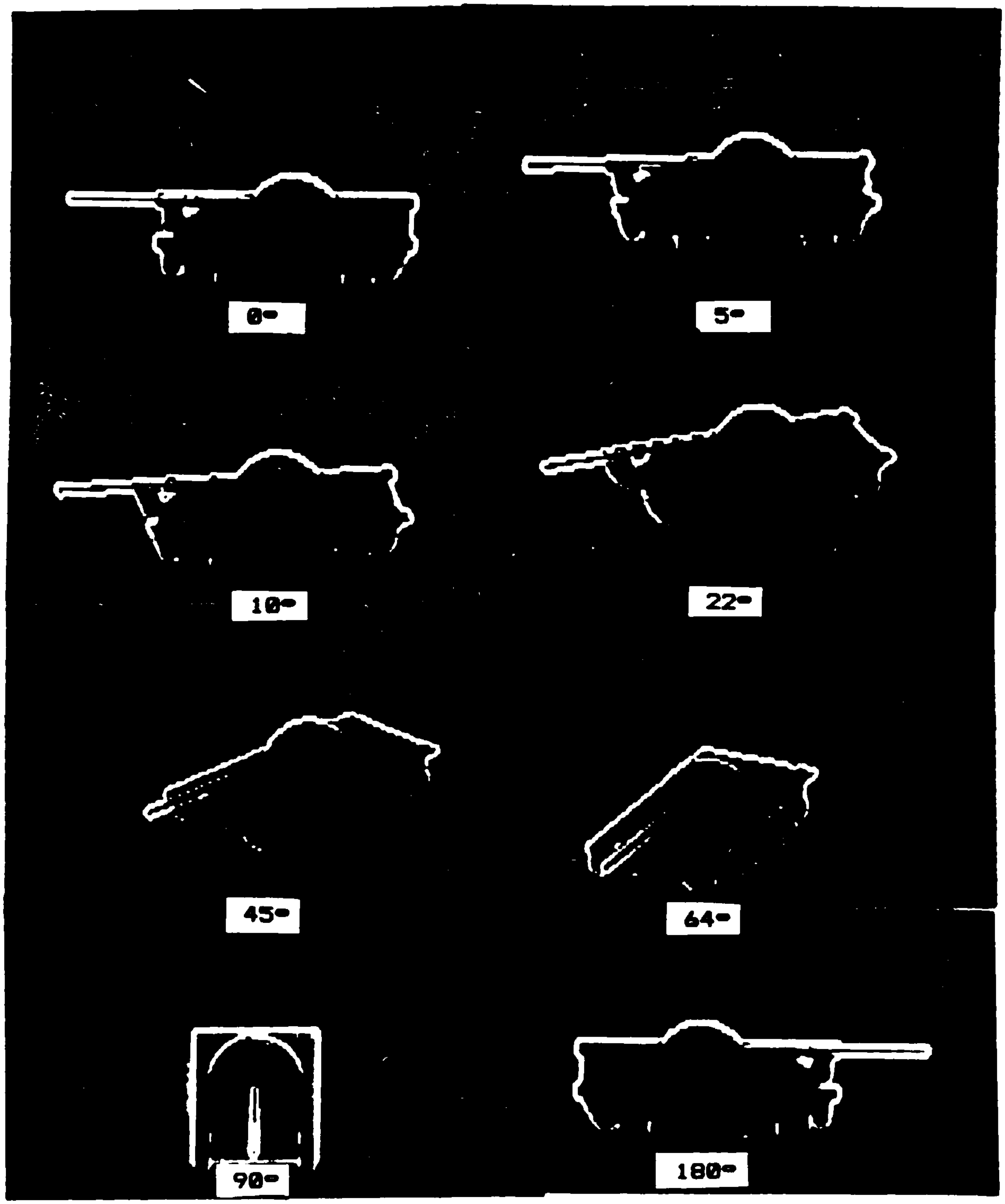

Figure 17. Edge Enhanced Range Images of Rotated Reference Tank (8.1 cm Spot Size)

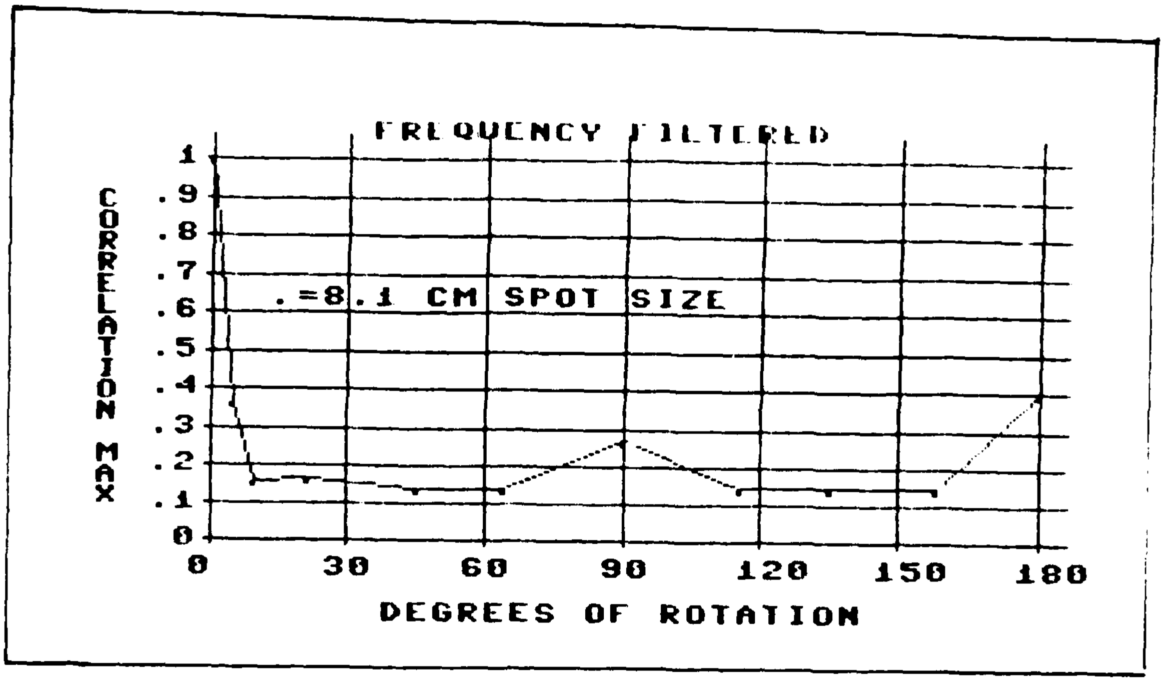

Figure 18. Correlation Maximums of Rotated T-72 Tank with Reference Tank (Frequency Filtered at 8.1 cm Spot Size)

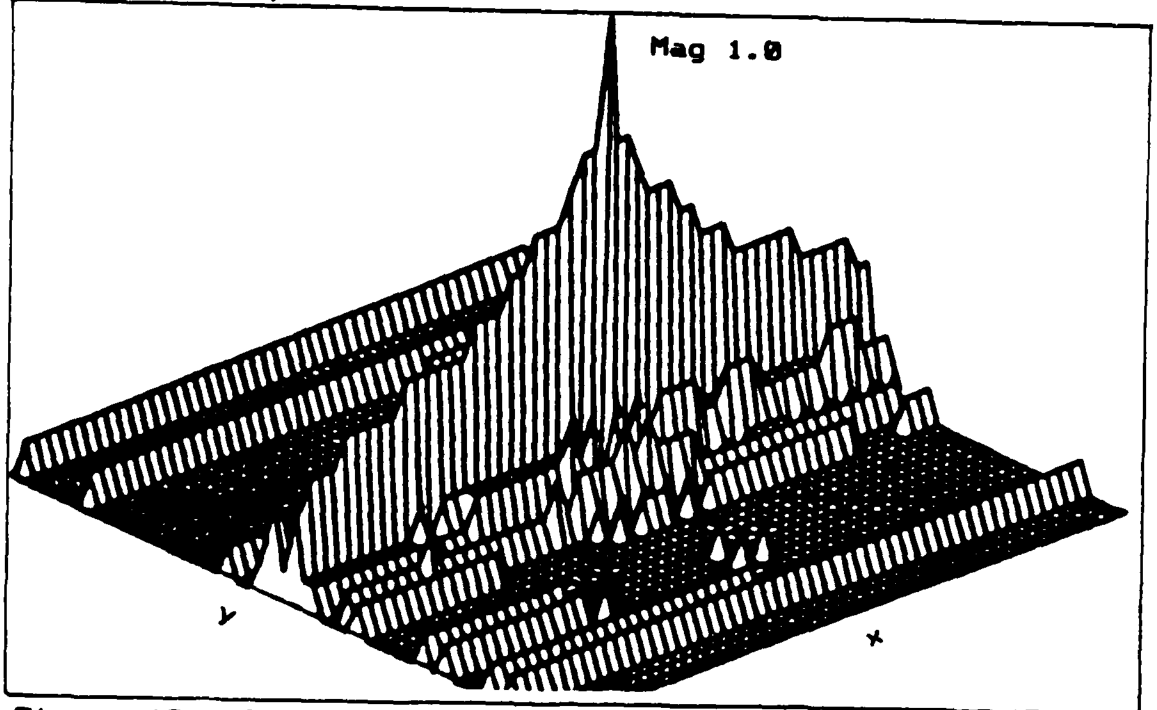

Figure 19. Auto-Correlation of Reference Tank Scanned at 16.2 cm Spot Size

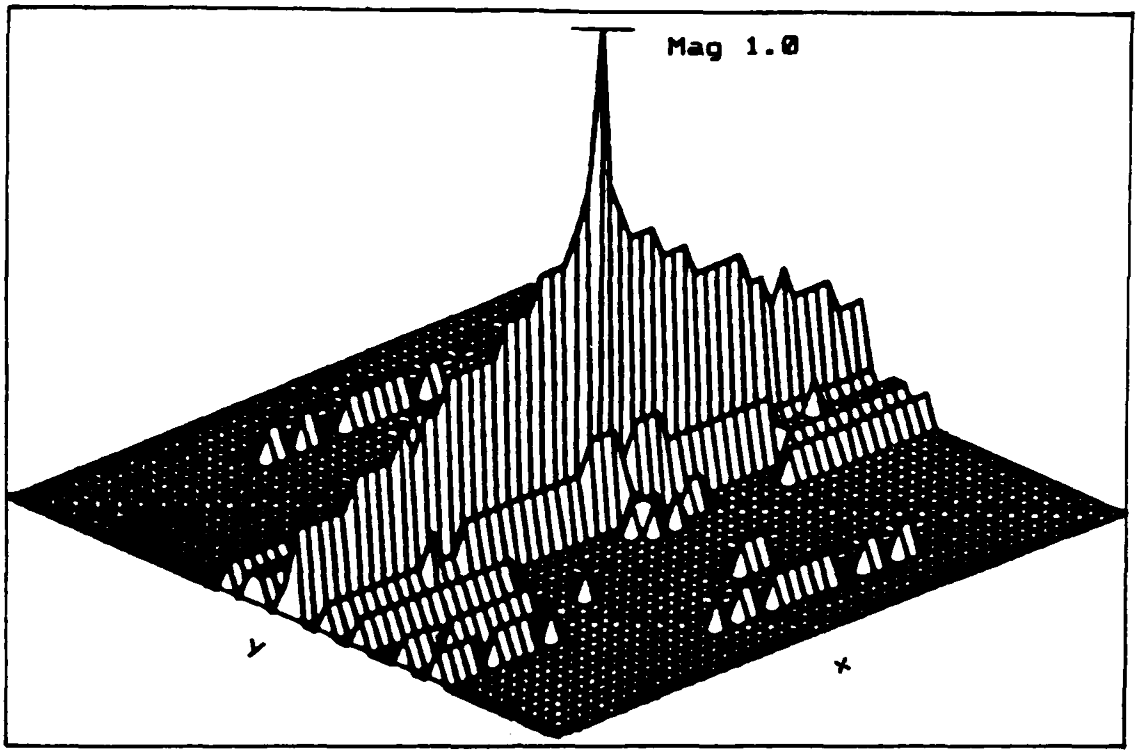

Figure 20. Auto-Correlation of Reference Tank Scanned at 8.1 cm Spot Size

correlation is much "cleaner", attributable to the smoother image. Figures 21 and 22 are the corresponding cross correlations for 45 degrees of rotation, and Figures 23 and 24 are the cross correlations for 10 degrees of rotation. Figures 25 and 26 are tops-down images of the 45 degree and 10 degree cross correlations at an 8.1 cm spot size. The 45 degree correlations exhibit a much wider spread than the 10 degree correlation, thus more of the energy is taken away from the central peak and the correlation maximum is lower. In comparing the central peaks of Figures 21 and 22 and Figures 23 and 24, the higher magnitudes in 21 and 23 are attributable to the

feature enhancement effect of the larger spot size. The more prominent gun tube, for example, increases, the maximum value of the correlation with the reference tank.

The 90 degree cross-correlation has a greater magnitude than most other orientations. This is attributable to the fact that much of its energy is aligned along the same axis as the reference tank. It does not exhibit a correlation maximum greater than the .3 value because as Figure 27 shows, a great deal of its energy is also aligned along the opposite axis.

All these cross-correlations exhibit a large number of noise peaks. These are due, in part, to the alignment of actual edges in one image with extraneous or noise edges in the other. Figure 28 is a high contrast image of the reference tank illustrating some of these edges. Each extraneous edge contributes to the lowering of the correlation coefficient. Weinhouse (22:68) suggests that correlation results should be improved by implementing a correlation method which minimizes the alignment of salient edges with extraneous edges. One means of doing this is to detect edge direction. A long, straight edge is characterized by a specific gradient, whereas noise edges tend towards random orientation. Weinhouse describes a "dot product correlation" method to accomplish this image correlation improvement. Again, any such additional processing takes time, generally not available

in a real time missile scenario.

Viewing the tops-down auto correlations of rotated images suggests that if an input image can be auto-correlated, its primary axis can be sensed and a coordinate transformation performed to align the reference and sensed image. In this manner a sensor could store the required reference filters and "call up" the one required. Such a process does add to the processing time but by utilizing optical processing techniques, this could be minimized (4:16).

Figures 29 and 30 shows the rotated images enhanced using the phase-only filtering technique. These were scanned at a spot size of 8.1 cm, and as Figures 31 and 32 indicate, correlation maximums are nearly the same as those found for frequency emphasized images. No advantage is indicated here towards rotational variance using phase-only filtering. The phase-only filtered images exhibit a high degree of similarity with the frequency emphasized images. The major noted difference is the apparent additional emphasis of the image corners.

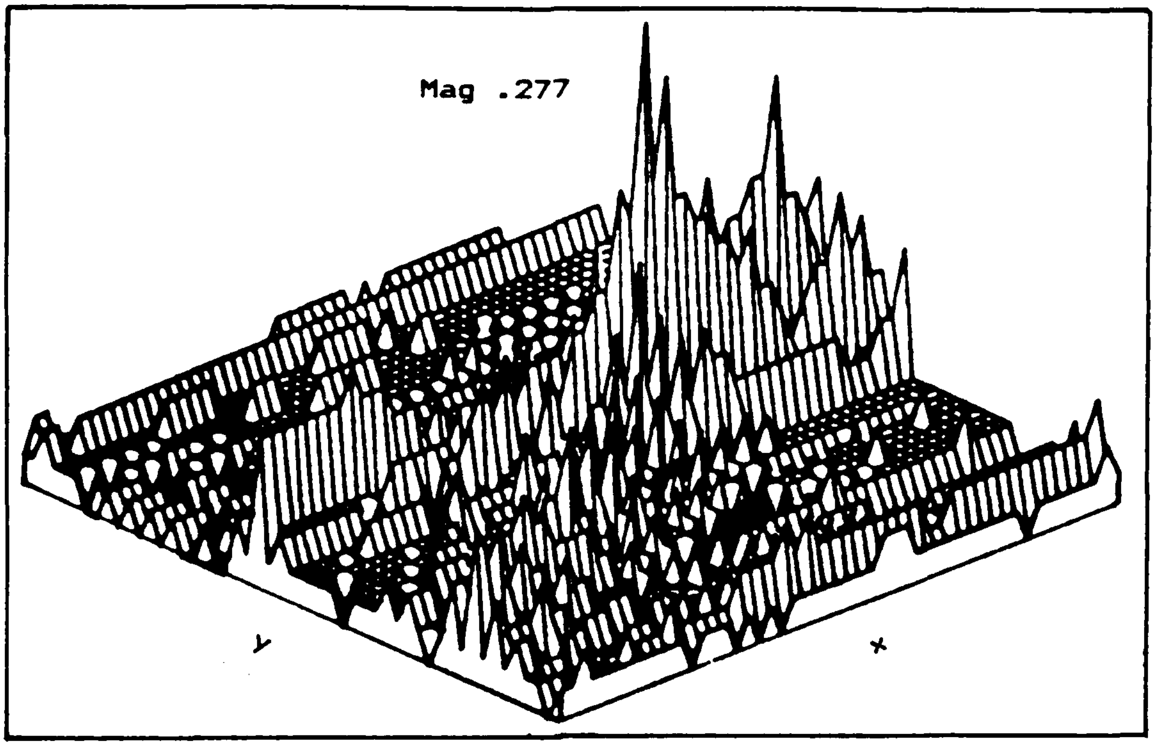

Figure 21. Cross-Correlation of T-72 Tank rotated 45 degrees with Reference Tank (16.2 cm Spot Size)

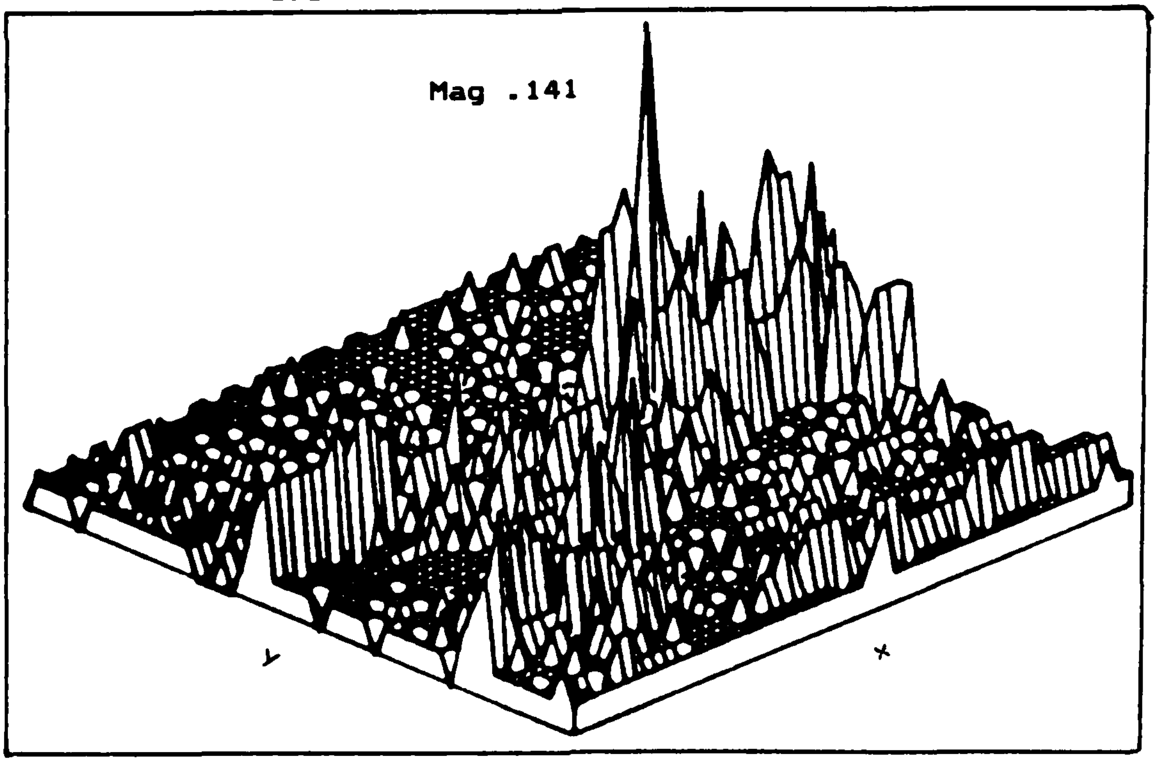

Figure 22. Cross-Correlation of T-72 Tank rotated 45 degrees with Reference Tank (8.1 cm Spot Size)

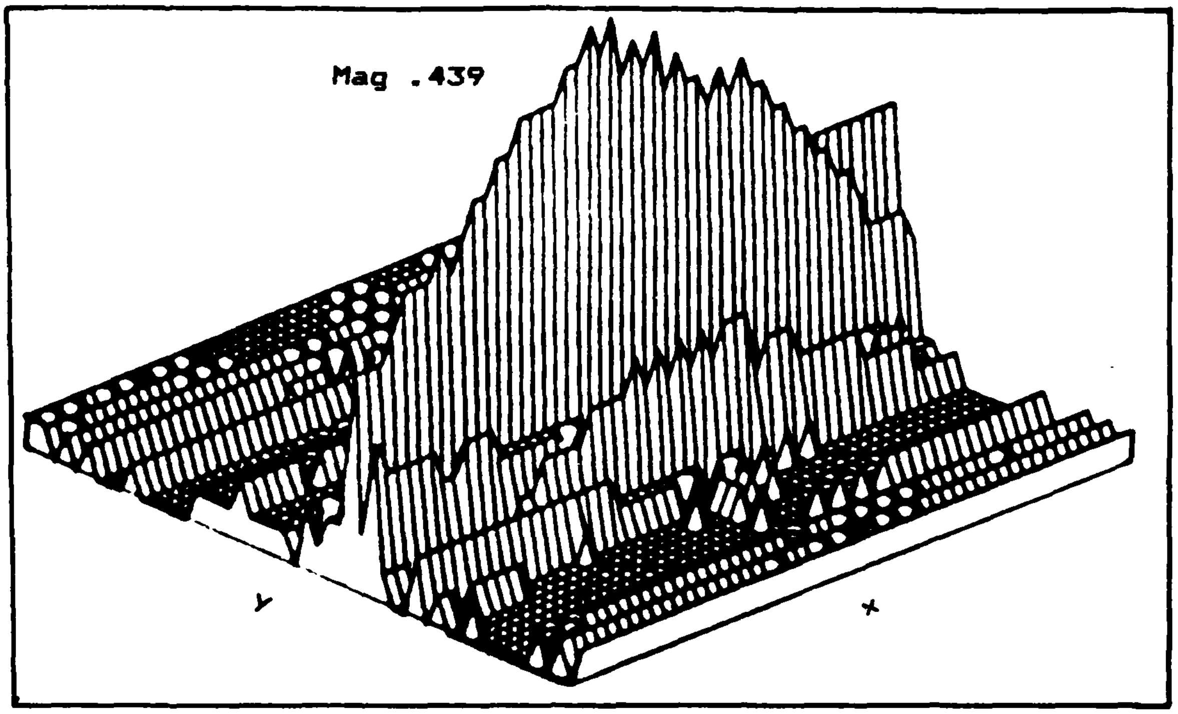

Figure 23. Cross-Correlation of T-72 Tank rotated 10 degrees with Reference Tank (16.2 cm Spot Size)

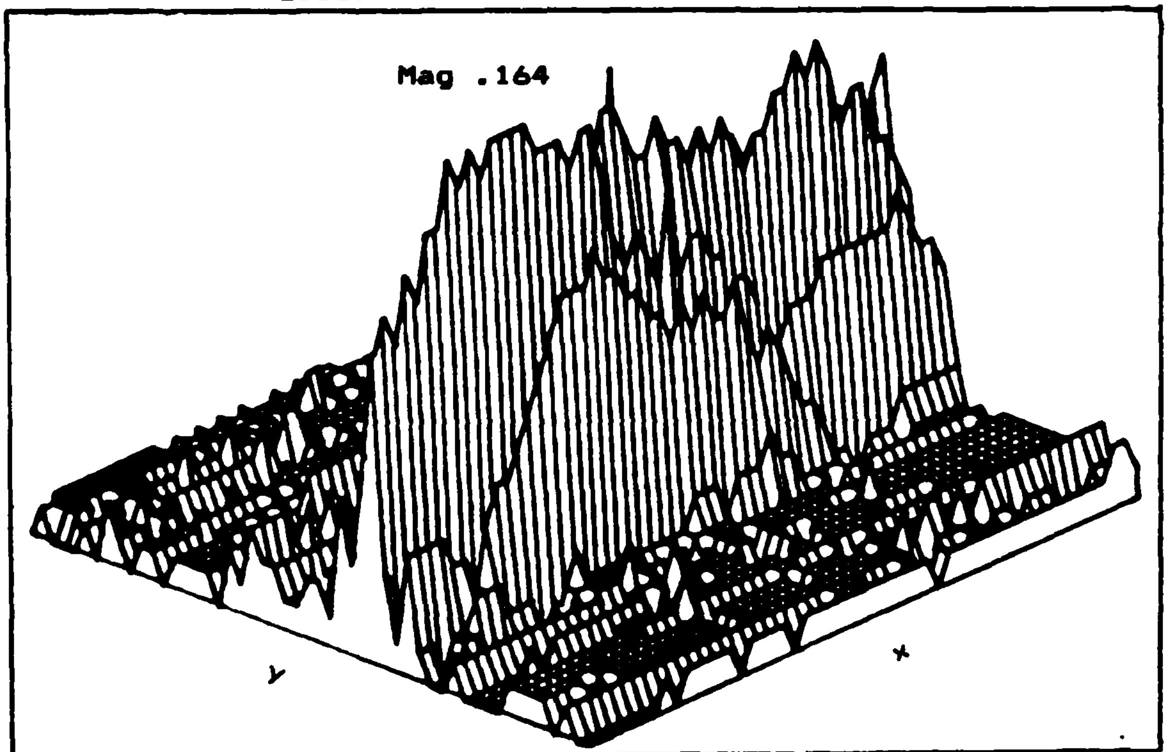

Figure 24. Cross-Correlation of T-72 Tank Rotated 10 degrees with Reference Tank (8.1 cm Spot Size)

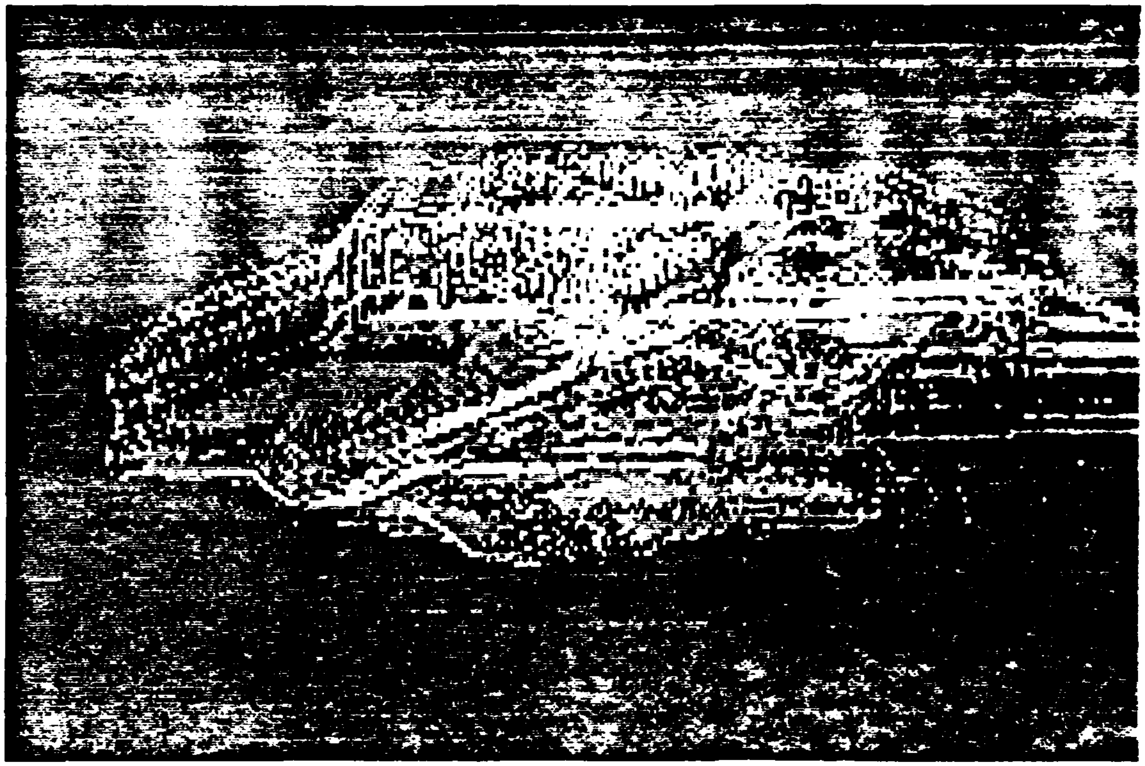

Figure 25. Cross-Correlation of T-72 Tank Rotated 45 degrees with Reference Tank (Tops Down, 8.1 cm Spot Size)

Figure 26. Cross-Correlation of T-72 Tank Rotated 10 degrees with Reference Tank (Tops Down, 8.1 cm Spot Size)

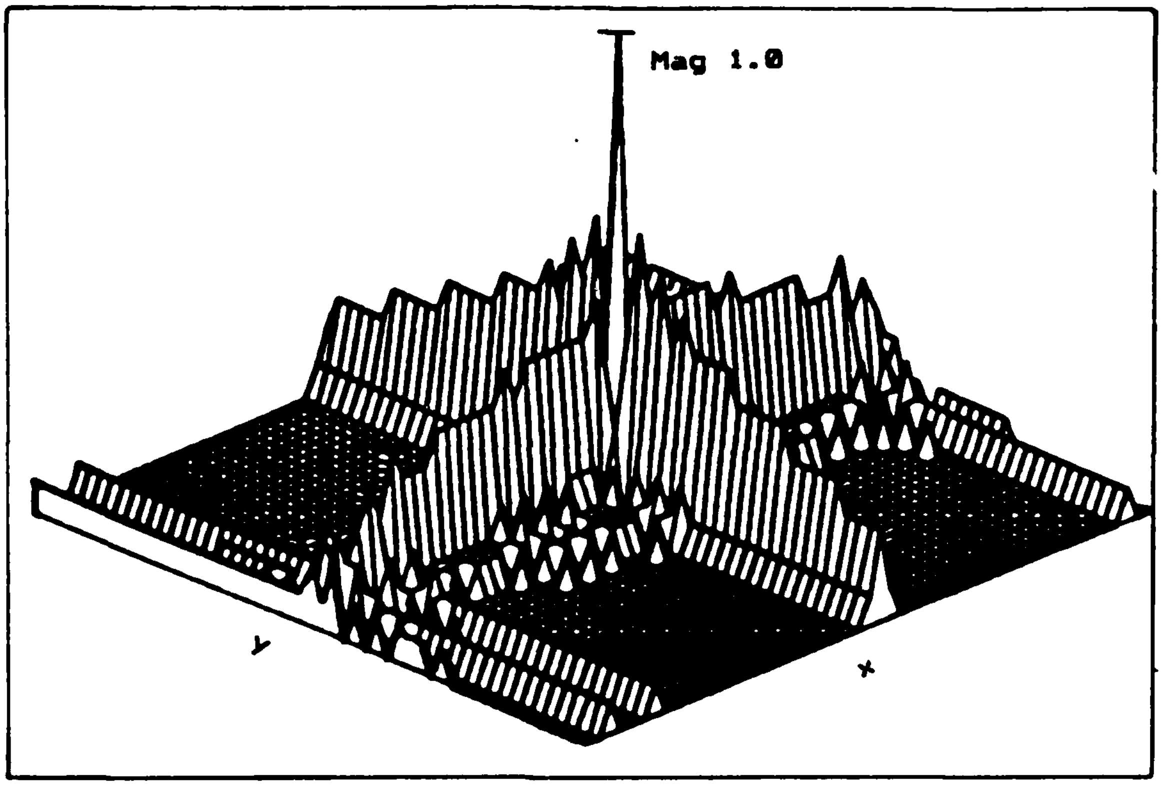

Figure 27. Auto-Correlation of a T-72 Tank Rotated 90 degrees (16.2 cm Spot Size)

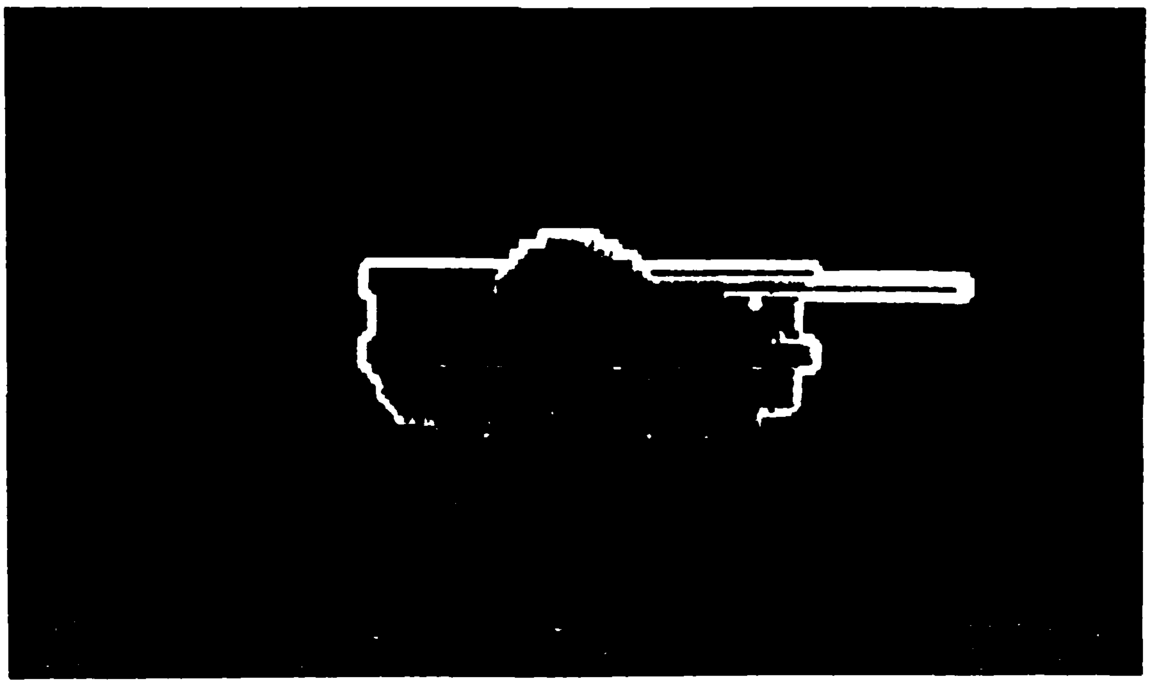

Figure 28. High Contrast Edge Enhanced Image of T-72 Tank

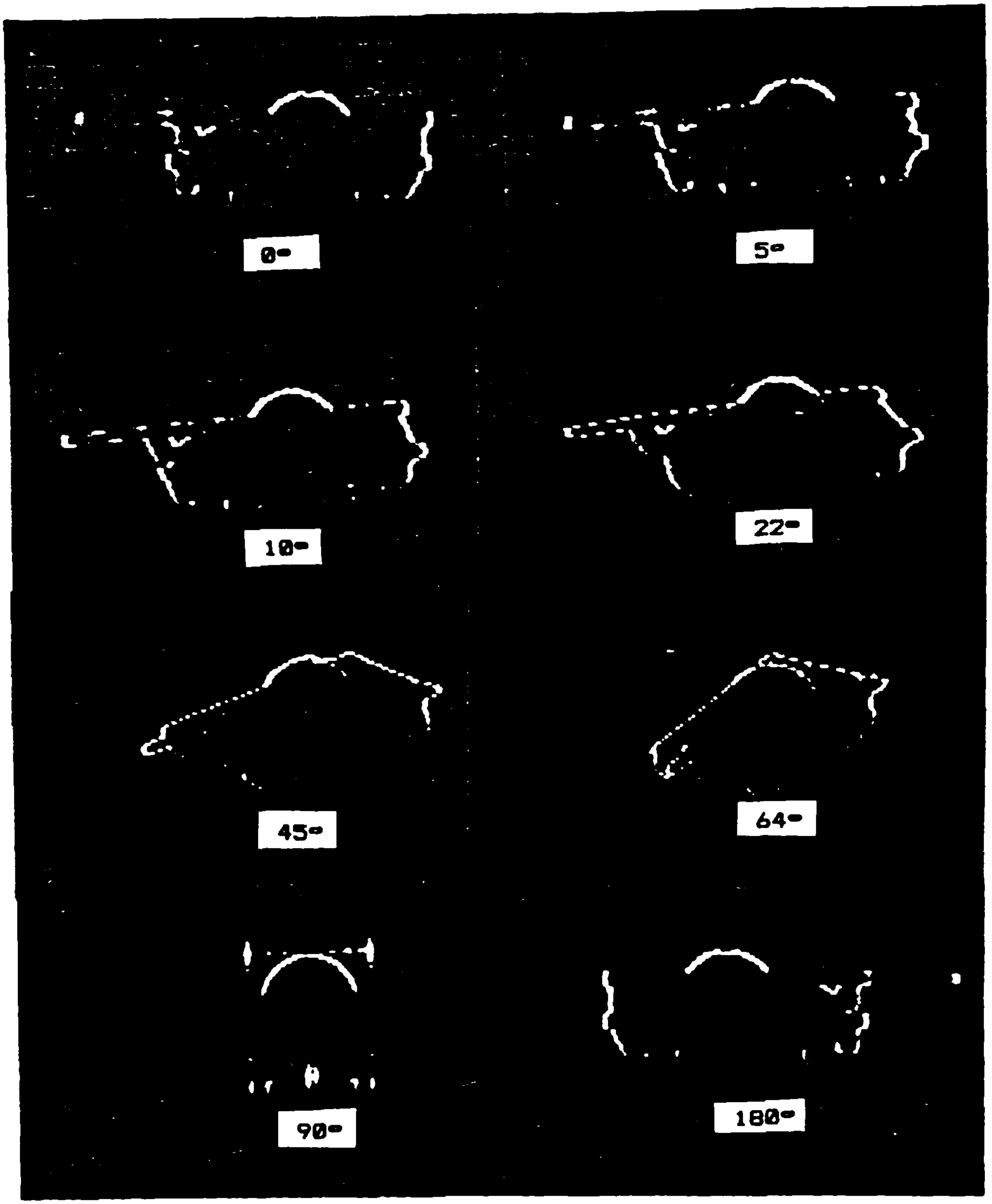

Figure 29. Phase-Only Filtered Range Images of Rotated T-72 Tank (8.1 cm Spot Size)

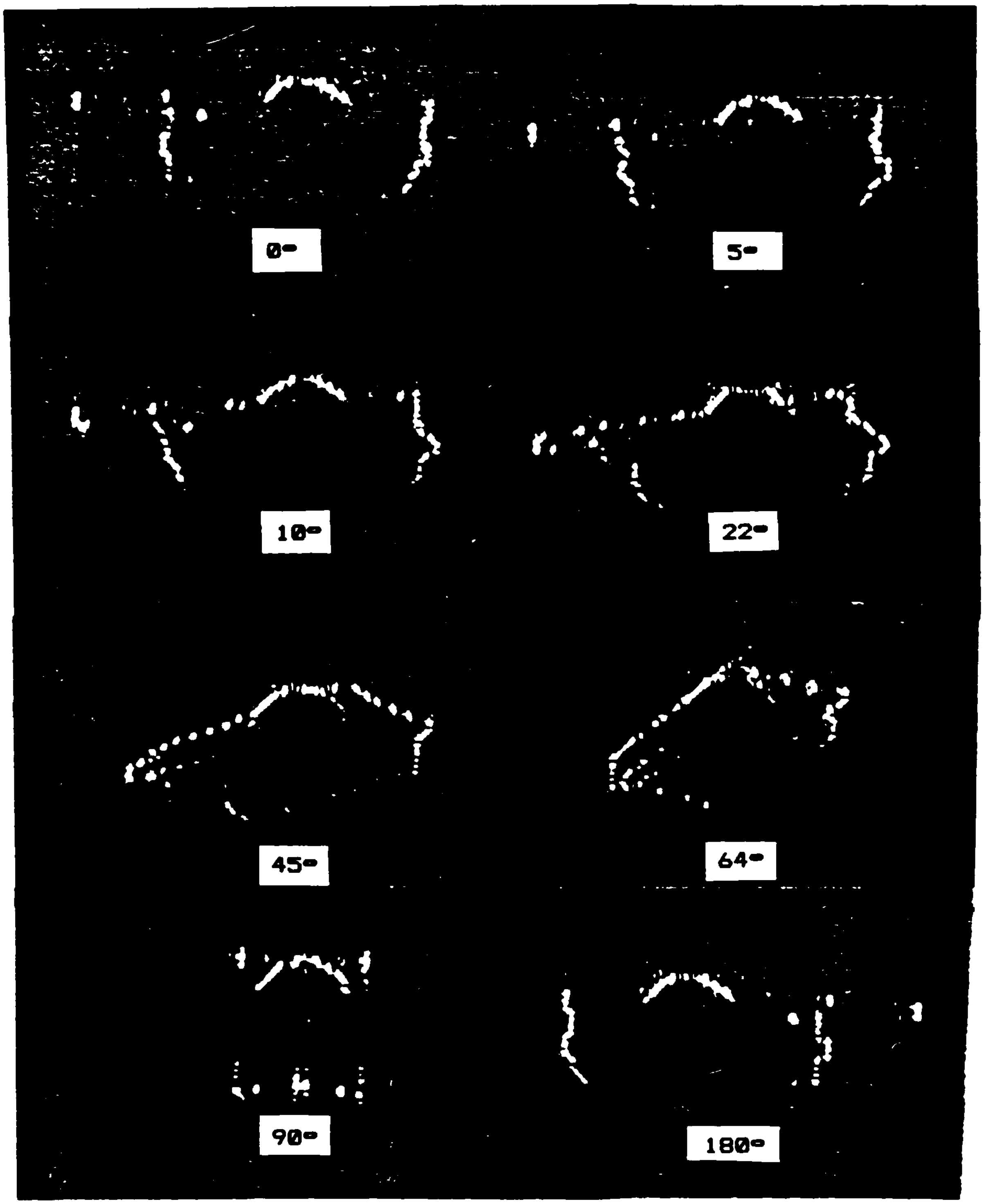

Figure 30. Phase-Only Filtered Range Images of Rotated T-72 Tank (16.2 cm Spot Size)

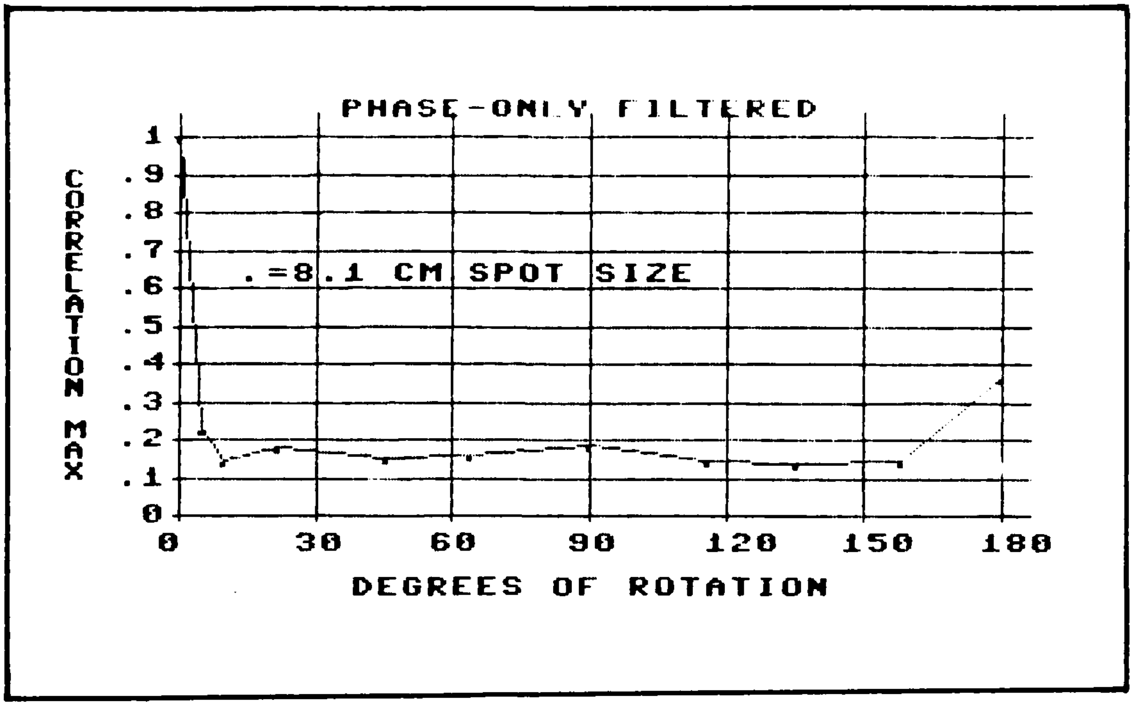

Figure 31. Correlation Maximums of Rotated T-72 Tank with Reference Tank (Phase-Only Filtered at 8.1 cm Spot Size)

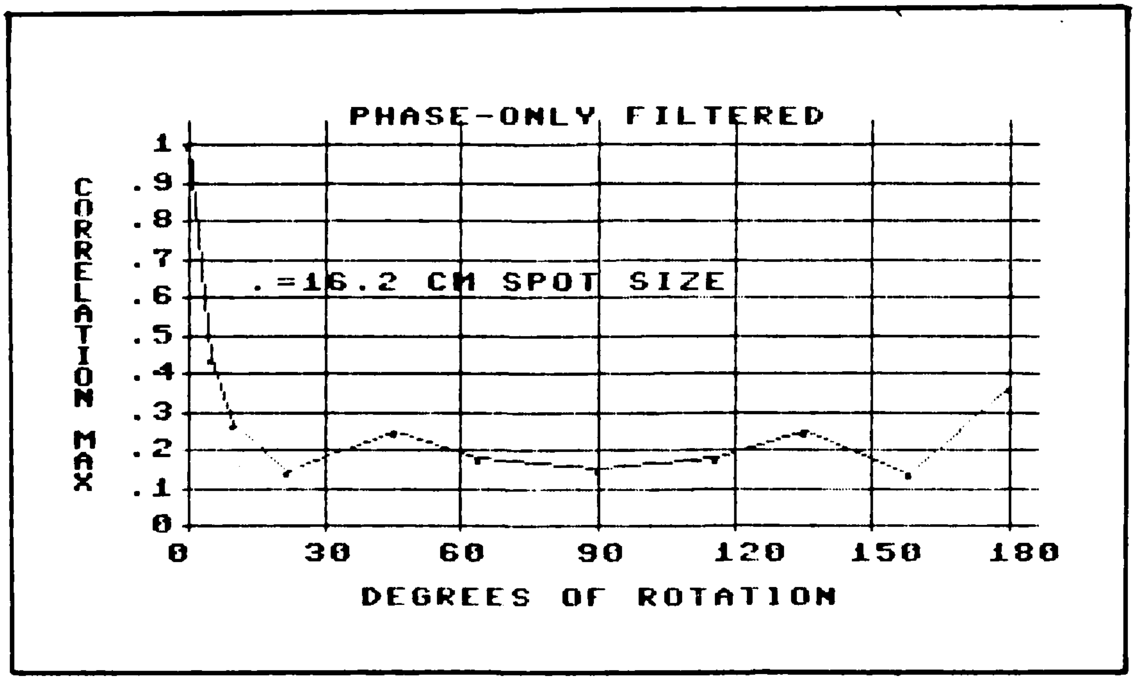

Figure 32. Correlation Maximums of Rotated T-72 Tank with Reference Tank (16.2 cm Spot Size)

Decoy Analysis

A logical attempt at defeating a range-only imaging seeker system would be to deploy a decoy. A suitable decoy would look enough like the real thing that the seeker would identify it as a viable target. Since range-only imaging is largely independent of material composition, shape is the primary discriminator. The analysis in this section takes into account the practicality of decoy deployment by limiting decoy complexity. The logistics and cost associated with deploying an extensive or sophisticated system of decoys would be prohibitive, so an assumption is that decoys would be relatively simple.

The composition of the three primary decoys imaged in this research is discussed in Chapter III. The three decoy set was imaged using both frequency emphasis and phase-only filtering at 8.1 and 16.2 cm spot sizes. Figures 33, 34, 35 and 36 illustrate the enhanced decoy images for each data iteration and the corresponding reference tank against which the images were correlated. The results of the cross-correlations are listed in Table I.

These results indicate that a threshold correlation coefficient of 0.751 is required to defeat the most sophisticated decoy (decoy 3) with the sensor in a 16.2 cm spot size, frequency emphasizing mode. However, there are

Table I. Correlation Maximums For Various Decoys			
	Decoy 1	Decoy 2	Decoy 3
Frequency Emphasized			
8.1 cm Spot Size	0.528	0.357	0.699
16.2 cm Spot Size	0.605	0.422	0.751
Phase Only Filtered			
8.1 cm Spot Size	0.128	0.548	0.598
16.2 cm Spot Size	0.162	0.532	0.610

additional considerations which are pertinent. The first is the implied ideal conditions under which the simulation is run to create the images for comparison. The second is the nature of decoy 3, which almost duplicates the actual reference tank dimensions. The turret and gun tube dimensions are identical to that of the reference tank. As will be shown in the next section, the gun tube is the most prominent feature in importance to the correlation. This implies that to defeat the proposed sensor, near duplication of the external dimensions is required, including both scale and shape. Simply decreasing the size of the image by 10% causes the coefficient to drop to 0.562, and it is unreasonable to consider an upscale decoy.

Altering the turret caused the correlation to be degraded. Replacing the spherical section comprising the turret in the decoy with a cylindrical turret, the same

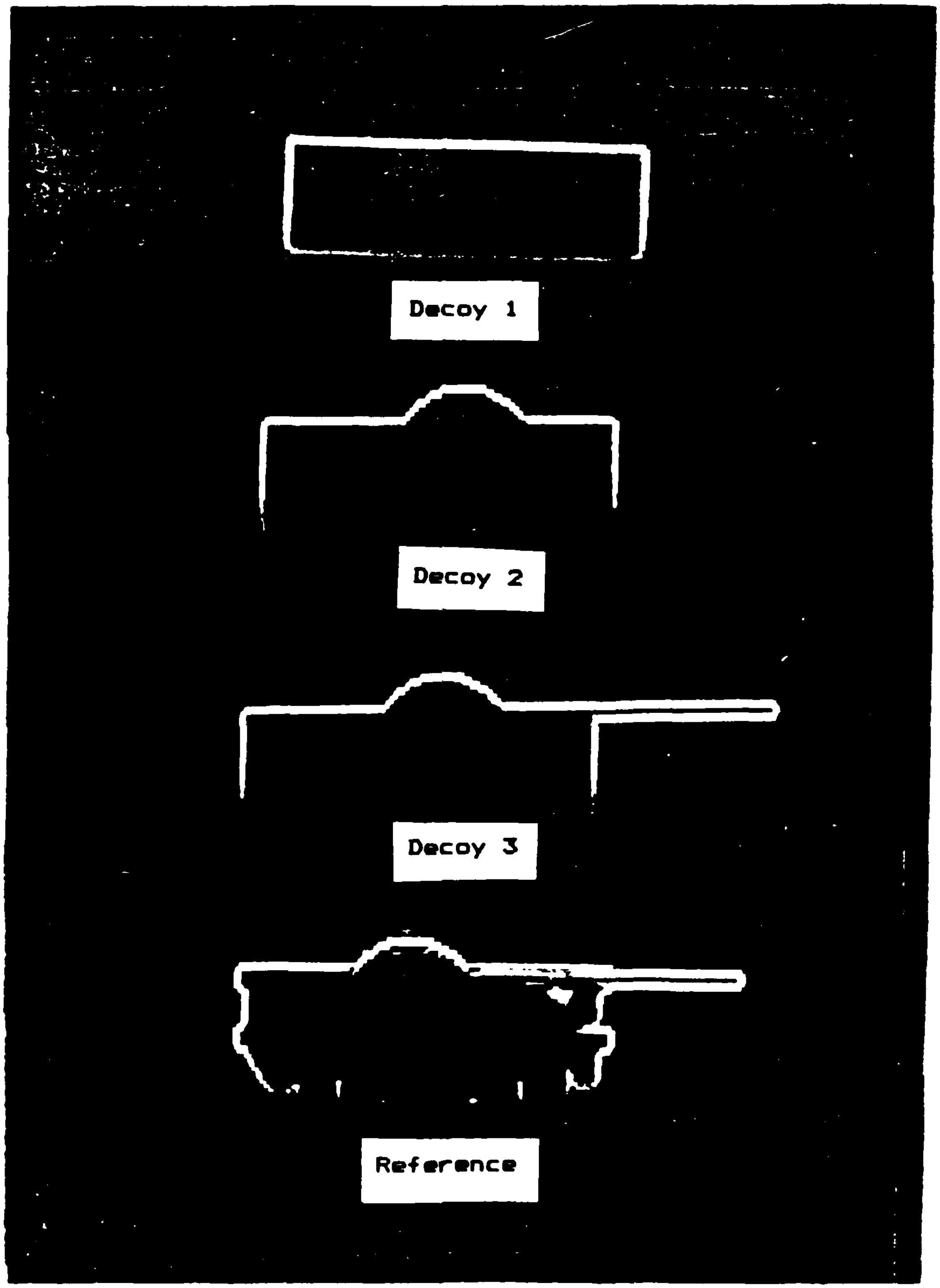

Figure 33. Decoy Image Set (Frequency Filtered, 8.1 cm Spot Size)

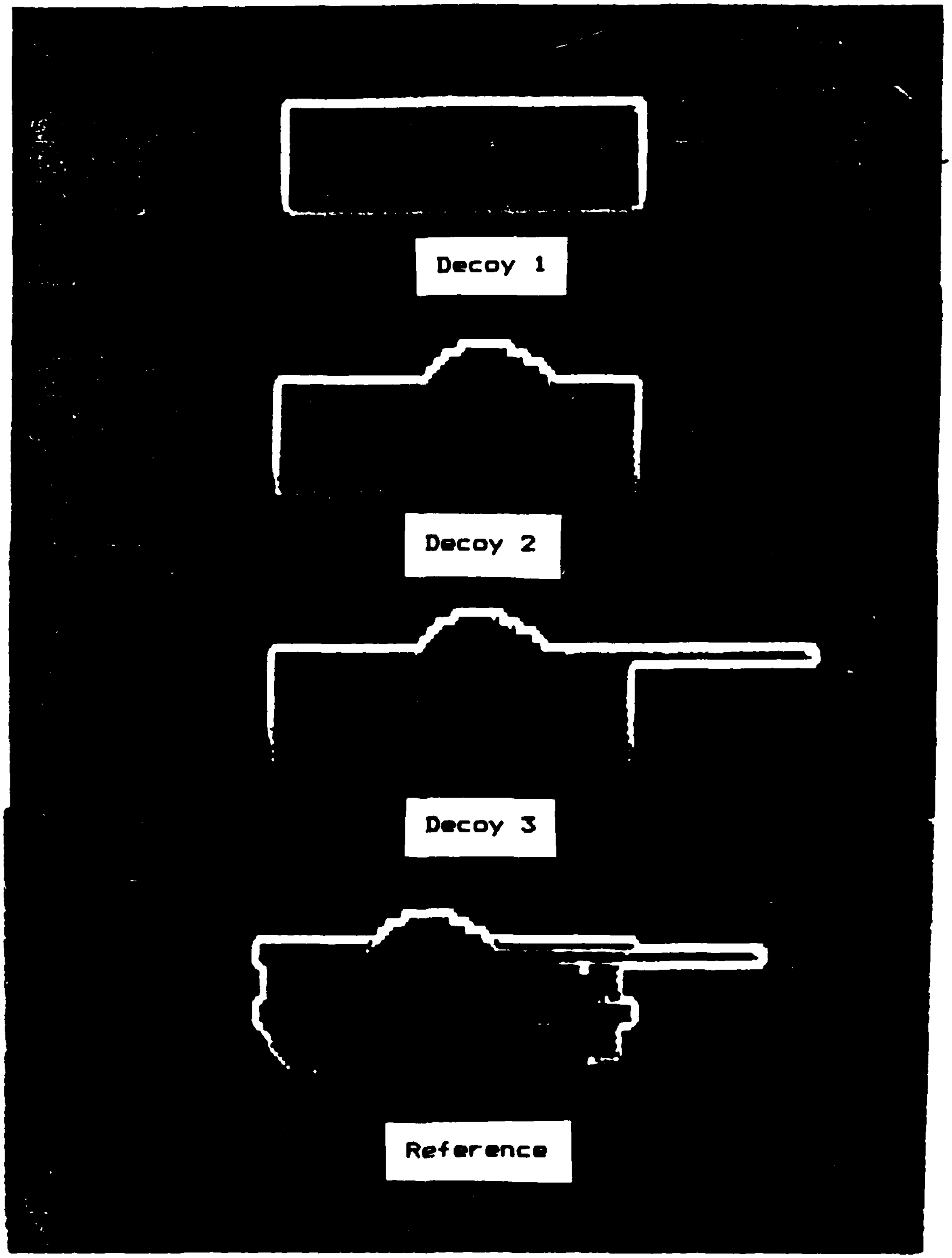

Figure 34. Decoy Image Set (Frequency Filtered, 16.2 cm Spot Size)

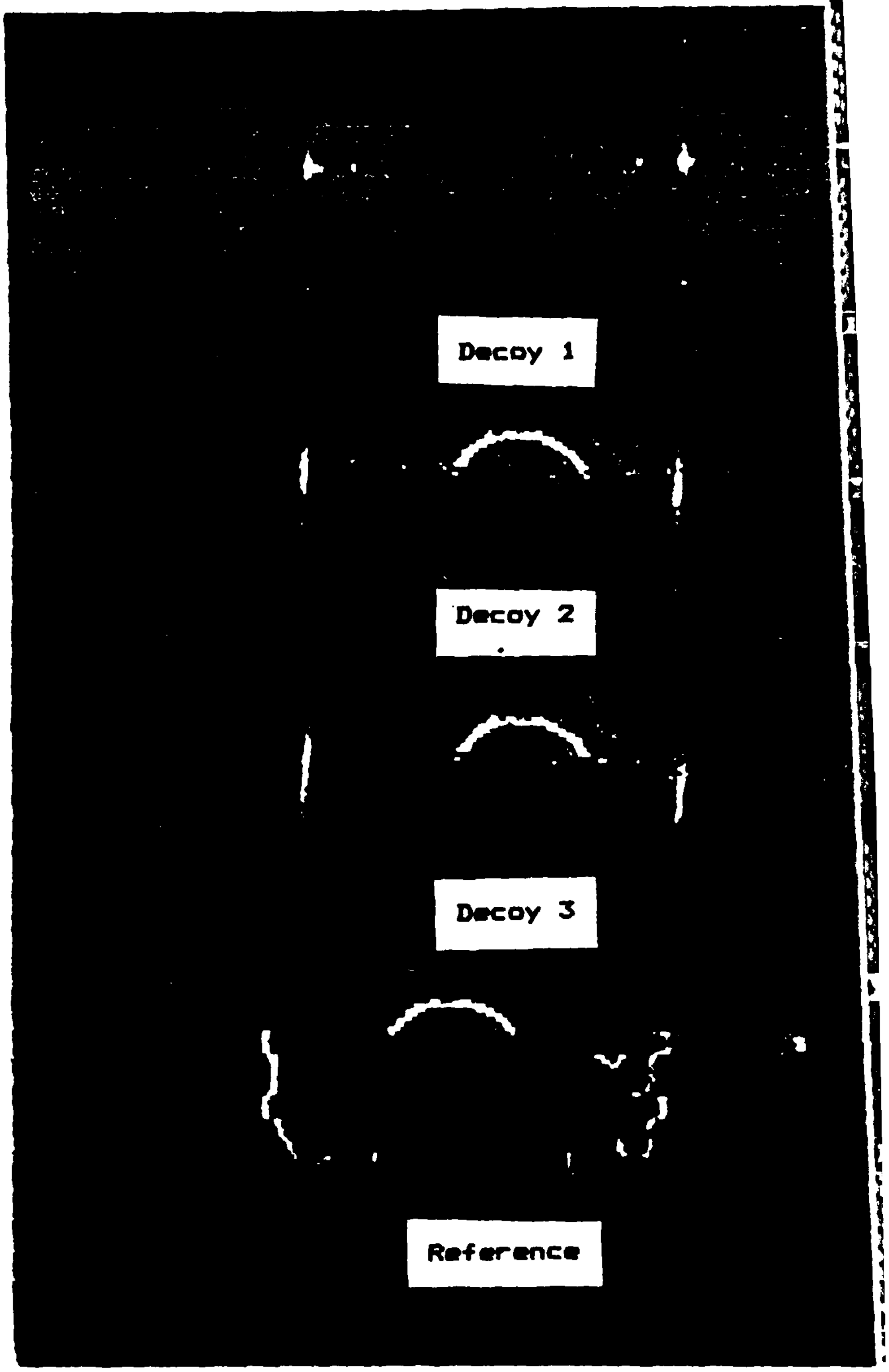

Figure 35. Decoy Image Set (Phase-Only Filtered, 8.
Spot Size)

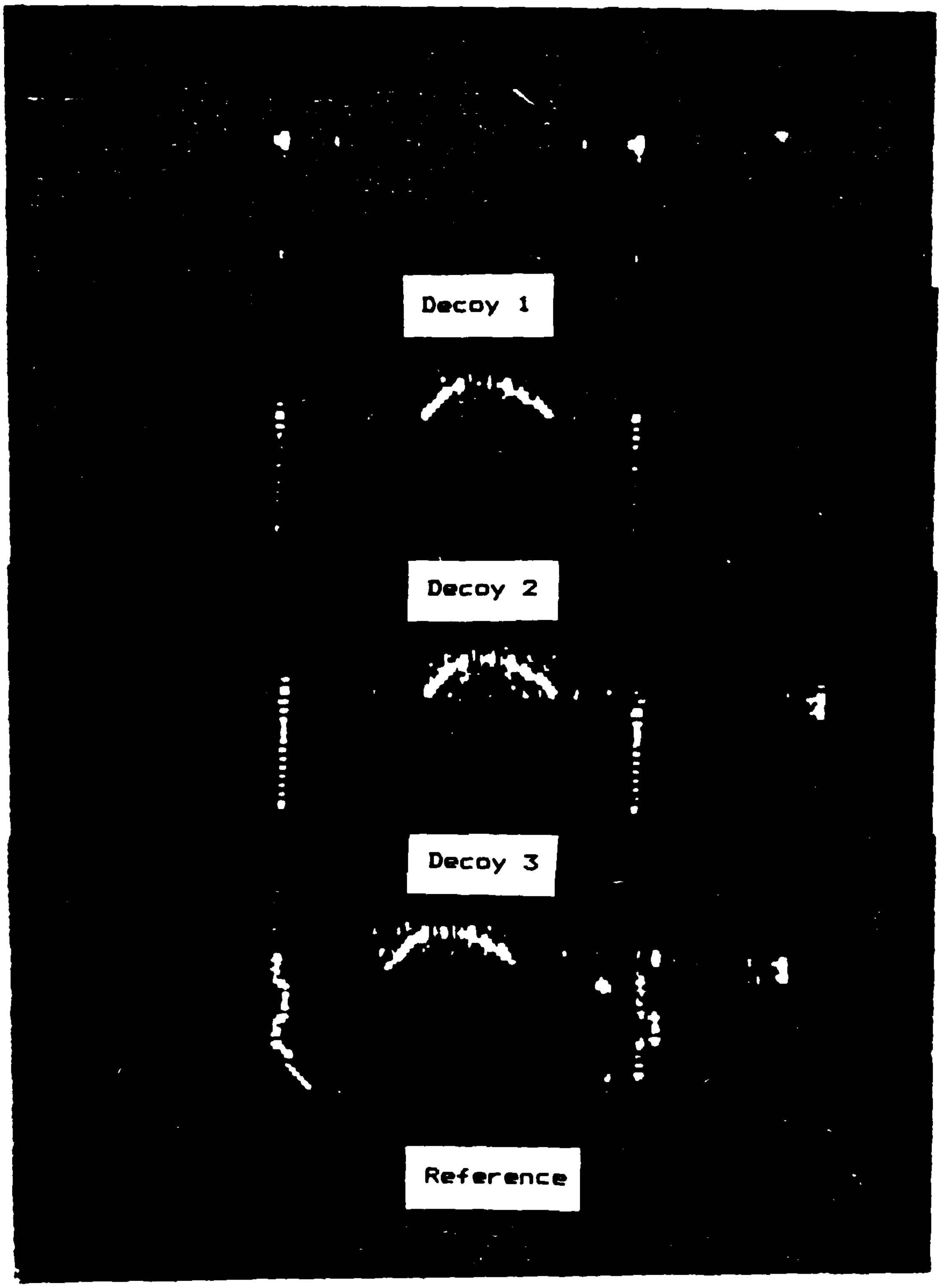

Figure 36. Decoy Image Set (Phase-Only Filtered, 16.2 cm Spot Size)

height and circumference as the spherical section, caused the correlation maximum to drop to 0.436. A rectangular box turret of similar dimensions dropped the correlation to 0.471 cm. The inherent similarity of the edge-enhanced cylinder and box scanned at a 20 degree depression angle causes the corresponding near-equal decline in the correlation maximums. The additional edge created by the flat upper surface of the box or cylinder is sufficiently great as to severly affect the correlation.

The previous section demonstrated the correlation's invariance to rotation. One condition implied in a 0.751 threshold is perfect orientation on flat ground. While the assumption is required for the simulation, real world scenarios dictate that a reduction in the experimental threshold value is warranted based on the random variational nature of the input conditions. Therefore, given the ideal conditions of the simulation it is not unreasonable that a decoy with near identical dimensions would have a relatively high correlation with the reference tank. Even higher correlations are not possible due to the complicated structure and resulting intricate edge enhanced image of the reference tank. This edge structuring creates a multitude of noise elements in the correlation. Figure 37 is the cross-correlation of decoy 3 with the reference tank. This correlation does not exhibit much of the side peaks evident in correlations

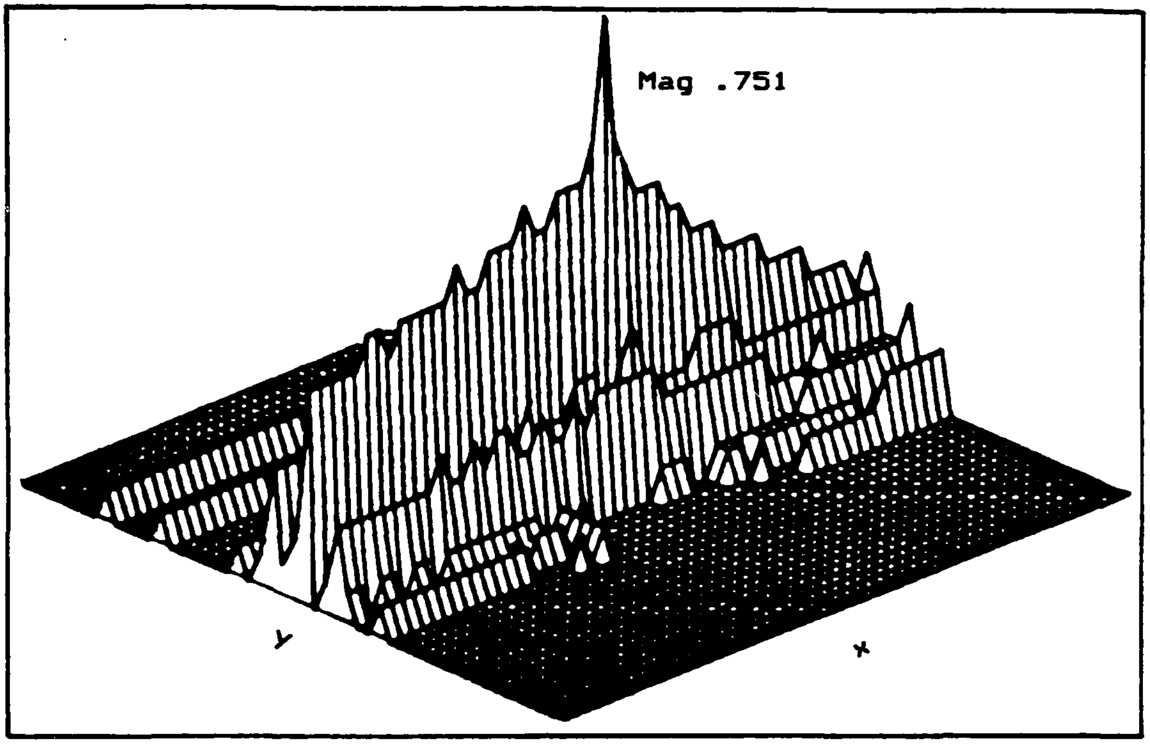

Figure 37. Cross-Correlation of Decoy 3 with Reference Tank

between two complicated images. Decoy 3 is a simple image without extraneous edges. It should also be noted that the cross-correlation is almost entirely unidirectional, as expected, since corresponding edges in both images are co- alined.

In looking at the other frequency enhanced decoy images' correlation maximums, it is apparent that decoy 2 is not a viable decoy. This is attributable to the absence of the gun tube. However, decoy 1, the simple box, did correlate fairly well with the reference tank. This is due to its long straight edges oriented in the same direction and nearly identical in length as those in

the reference tank.

Phase-only filtering results differ greatly with those for frequency filtering. Examining the enhanced images, the most likely reason for this difference is the gun tube. Though emphasized, it is not nearly as prominent as in the frequency enhanced images. Decoy 1's image, typically, is enhanced most in the corner regions. The resulting similarity with the reference tank, intricate in its corner elements, is low. Using phase-only filtering, it appears that the most prominent feature of the correlation is the turret. The addition of the turret for decoy 2 raised the correlation magnitude significantly, and the further addition of the gun tube for decoy 3 only improved the correlation magnitude slightly. Additionally, from an examination of the images (Figures 35 and 36), the turret provides the most salient edge for a phase-only filtered range image. To test this, the cylindrical turret described earlier was substituted in decoy 3. The modified decoy 3 was then cross-correlated with the reference tank and the resulting correlation maximum dropped to 0.213, thus confirming thac the turret is significant in determining the correlation maximum for phase-only filtered tank images. The gun tube, apparently, is not a significant factor in phase-only filtered images.

This conclusion suggests different applications for

the two types of image enhancement methods studied. Frequency filtering would be most effective and appropriate where the mission of the sensor is to discriminate between classes of targets (example: tank versus not-a-tank), and the phase-only filtering would be most effective discriminating or recognizing within a class of targets (example: Soviet versus U. S. tanks). Grantham found that a horizontal cylinder approximately the size of the gun tube had a high correlation (0.630) with his tank (9:69). This object was meant to simulate a tree lying on the ground. The same object, when frequency filtered for enhancement, and cross-correlated with the reference tank, resulted in a correlation maximum of 0.544. Although this is below the level where an image would be accepted as a tank, by switching to phase-only filtering, the correlation maximium was dropped to 0.169. This represents a substantial improvement. Similar results were obtained for other simple objects placed in the range scene. Indications are that some combination of the two filtering methods would serve to enhance the seeker's capability in rejecting decoys and spurious objects in the range scheme as potential targets.

Feature Extraction

As an extension of the pattern recognition research area, feature matching methods are being tested. In

feature matching, instead of attempting to recognize an entire object, features of an object are identified as being unique or highly indicative of the presence of that object. The goal of feature extraction is to select features that are effective in discriminating between pattern classes (example: a tank versus not-a-tank). A feature can be defined as some characteristic or measure of an object that is somehow derived from the initial measurement. The object, therefore, is to select those features of the original detected image that can be used efficiently to recognize a target (14:31).

Feature extraction methods are highly problem dependent. The selection of the best features for recognition is dependent on the imaging system characteristics in addition to target parameters. The reasons for exploring feature matching are based in hardware and software economics. Boland (2:32) states that in order to reduce computation time and hardware requirements, the actual matching process should be based on the dominant image features and not on image gray level or edge content. In general, feature matching algorithms require fewer arithmetic operations and hardware for real-time implementation than object recognition techniques such as image correlation. Feature matching methods are especially adaptive to multiple target recognition problems. In the specific area of multiple

image recognition where a smaller image is to be detected in a larger image using "windows" in the larger image it has been shown that feature matching is computationally more efficient than image correlation if the number of windows is sufficiently large (14:5). The amount of computations required for image correlations is directly proportional to the number of windows. In feature matching algorithms features are extracted once for all windows and the matching procedure is repeated once for each window. The amount of computation required to match the features is extremely low compared to that required to compute the features. Therefore, the more windows involved, the greater the efficiency.

Given the potential of feature matching, this research was extended to examine the feature extraction possibilities inherent in the reference tank. In other words, just what features, if recognized, could be considered indicative of a tank being present. Intuitively, the answer is obvious: the gun tube is the most prominent feature of any tank. To test this hypothesis, an experiment was devised to measure the reliance of the correlation on each distinctive component of the reference tank. A full-up reference tank was sequentially stripped of its characteristic features and cross-correlated with a complete reference tank. The corresponding drop in the correlation maximum and

examination of the correlation plots help quantify the importance of each piece. Analysis here was limited to frequency filtering, as it was shown in the preceding section that phase-only filtering causes the prominence of the gun tube to be minimized.

Five image reduction levels were chosen; 1) full-up, 2) deletion of road wheels, 3) deletion of side skirts, 4) deletion of gun tube and 5) deletion of turret (bare tank hull). The images were correlated with the reference tank and resulting correlation maximums are plotted as Figure 38. The "no-wheels" tank still correlates at a 0.98 level. This is to be expected since the wheels do not

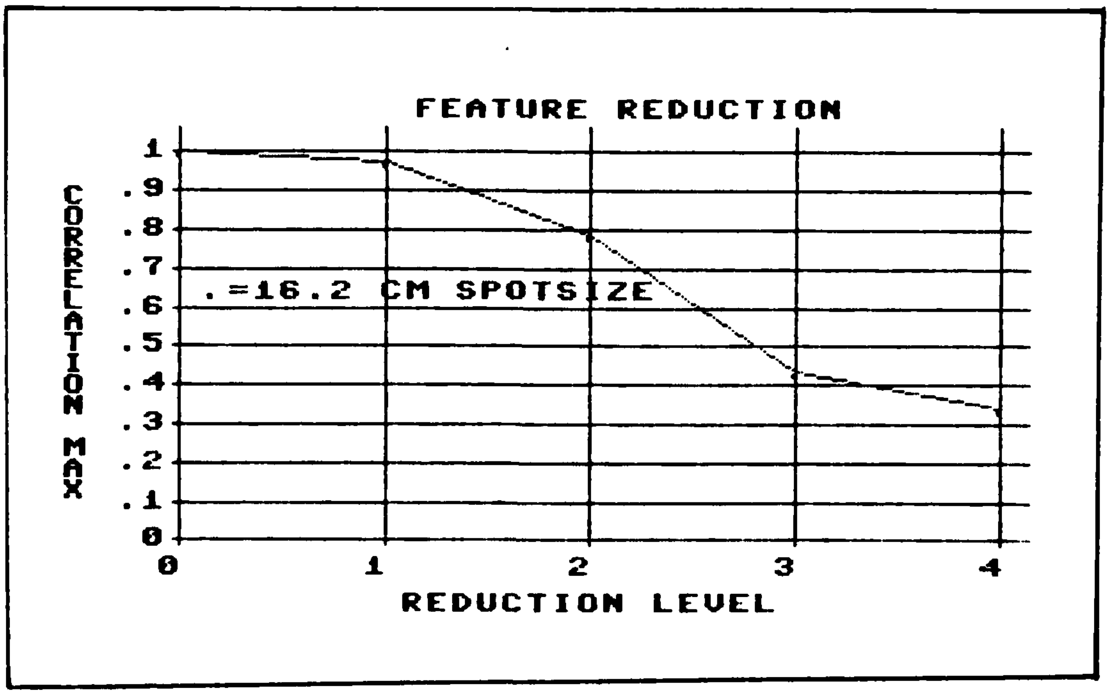

Figure 38. "Reduced" Tank Correlation Maximums

contribute any significant or extended edges. The skirts do contribute a significant amount of energy to the image's edge-enhanced outline. Deleting this feature results in a reduction of 0.193 to 0.786, still fairly high. Deletion of the gun tube drops the correlation maximum to 0.438, a reduction of 0.348. This constitutes the greatest drop in the correlation and tends to support the hypothesis that the gun tube is the most prominent correlation feature.

Figure 39 is the cross-correlation of the "no-wheels" tank with the reference tank. Its form is virtually indistinguishable from the reference tank's

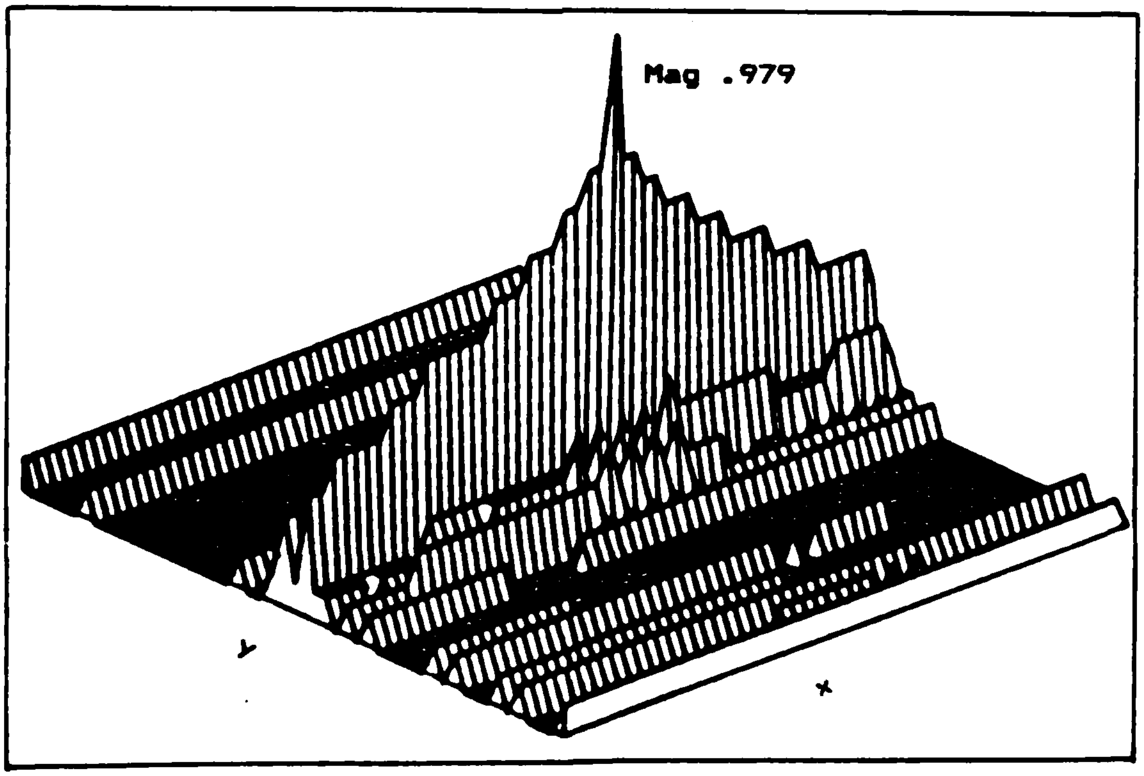

Figure 39. Cross-Correlation of Reduction Level 1 Tank With Reference Tank

auto-correlation (Figure 19). Figure 40 is the cross-correlation resulting when the tank is further reduced by the side skirts. The width of the central peak is increased and a corresponding decrease in the sharpness of the peak occurs (0.979 to 0.786). Due to the loss of the long edge from the front side of the tank the correlation does not have as substantial an "on center" area of overlap. Figure 41 is the resultant cross-correlation when the model is further reduced by the gun tube. Dropping below the level where recognition is considered (0.438), the central peak area is highly spread and noise peaks are increased. Figure 42 shows the tops down correlation view for reduction level 1 and reduction level 3 tanks cross-correlated with the reference tank. This clearly illustrates the spread of the correlation energy causing the reduced central peak. Table II lists several other iterations in the object reduction examination.

Table II. Reduced Object Correlation Maximums

Condition	Correlation Max
Without turret only	0.992
Without skirts only	0.795
Without gun tube only	0.731
Without turret, gun tube	0.636

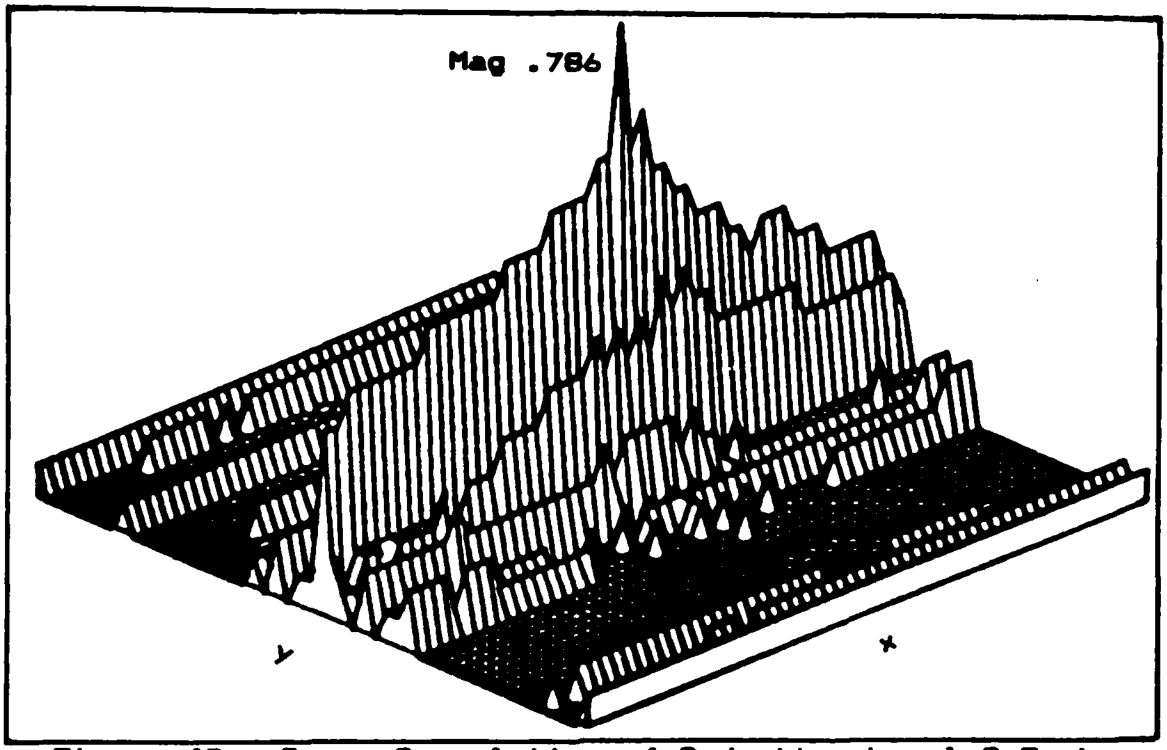

Figure 40. Cross-Correlation of Reduction Level 2 Tank With Reference Tank

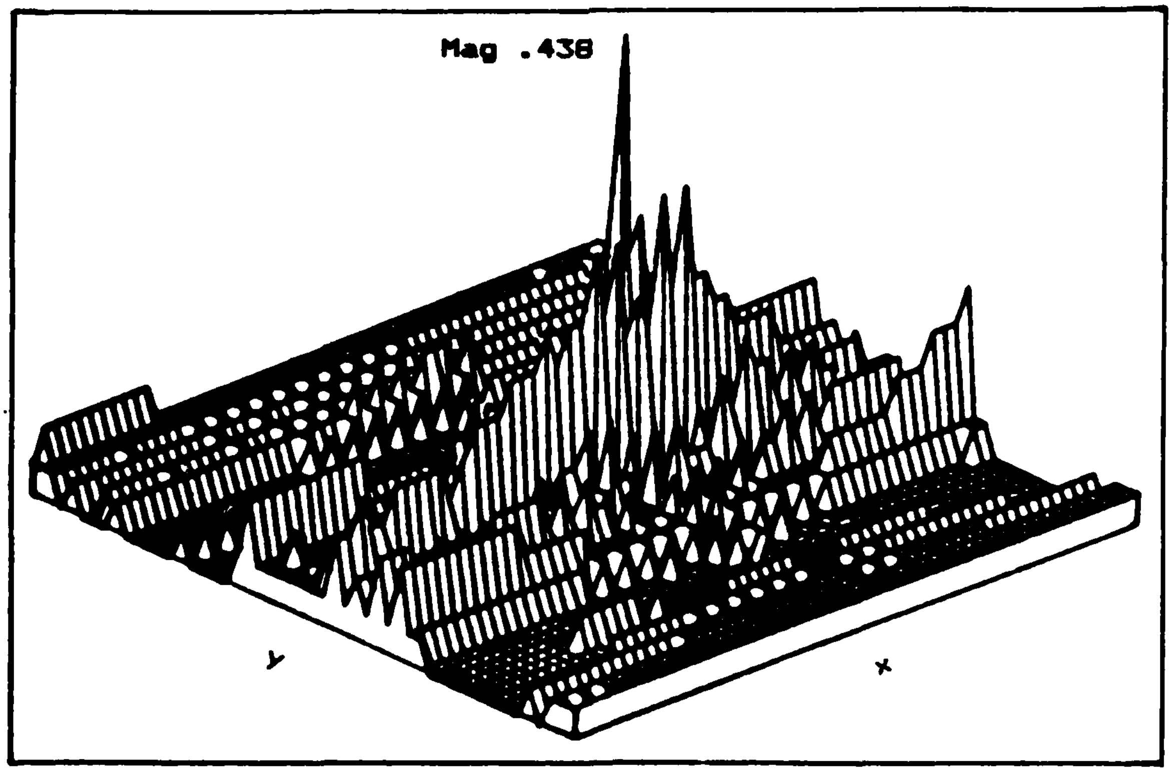

Figure 41. Cross-Correlation of Reduction Level 3 Tank With Reference Tank

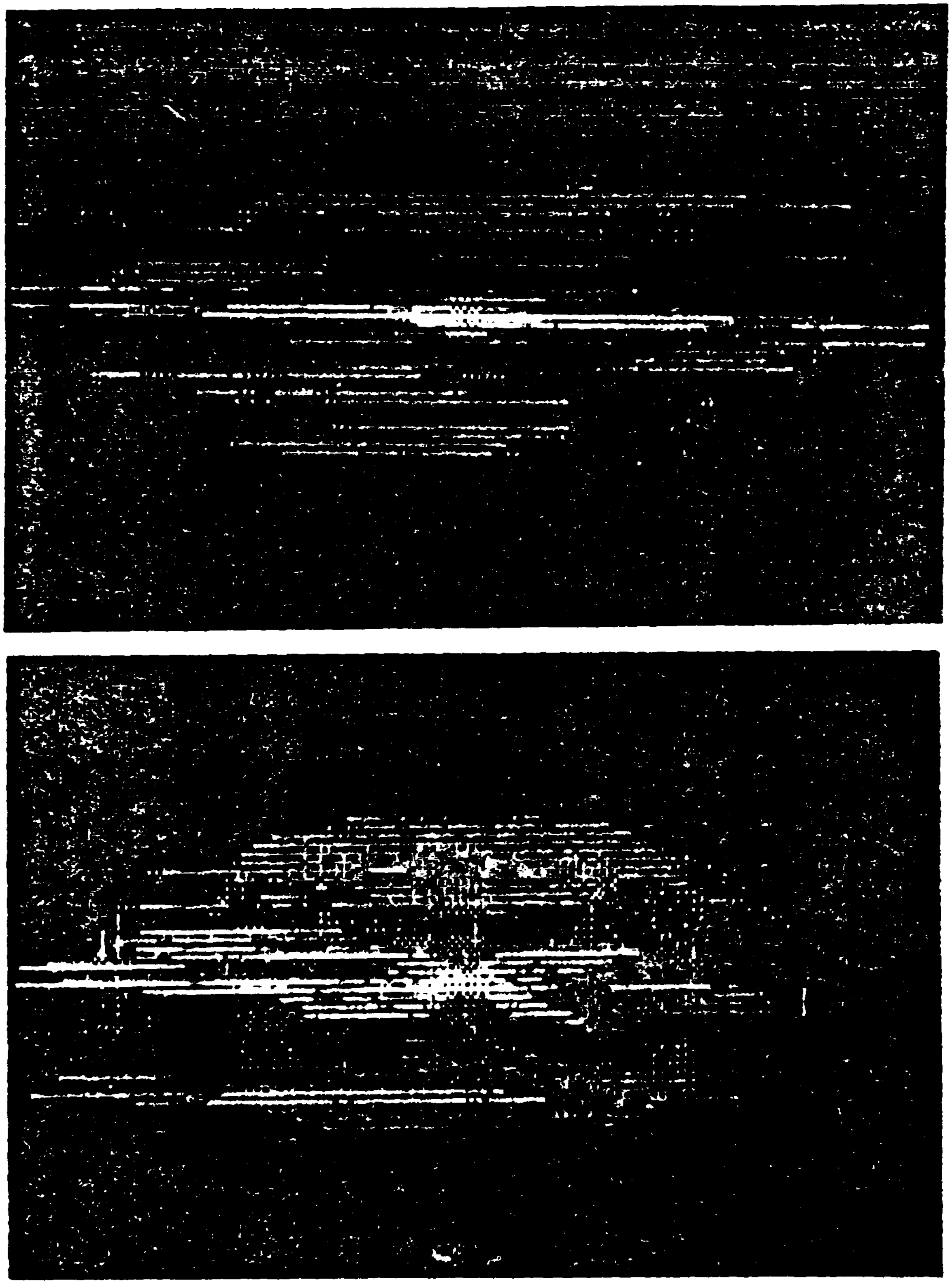

Figure 42. Cross-Correlation of Reduction Level 1 and Reduction Level 3 Tanks with Reference Tank (Tops Down)

Although it was shown that altering the turret shape degraded the corresponding correlation maximum, Table II shows that deleting the turret has virtually no effect. Overall data supports the hypothesis that the gun tube is the most important feature of the tank for the purpose of target recognition through cross-correlation using frequency filtering for emphasis. Loss of the side skirts causes a similar decline in the cross-correlation magnitude. A feature matching algorithm would exploit these results by searching for the presence of the gun tube, side skirts, or some combination of the two features.

Additional Discussion of Multisensory Imagery

Some of the more resent studies in the field of pattern recognition have been concentrated in the area of combining range imagery with intensity images to derive the structure of three-dimensional objects. Magee (13:146) enumerates the research efforts in this area. Though this type of multisensory imaging has not been emphasized as a recognition technique, recent results indicate that using intensity to guide range sensing may be useful in the area of object recognition (12:550).

The advantage of intensity imaging is the speed at which it can be obtained (typically 30 frames per second). Because intensity images are actually two-dimensional

representations of three-dimensional scenes, the third dimension is difficult to obtain without utilizing a system of multiple orientations. Range images readily provide the third dimension, and visible structure can be reconstructed from a single range image. Range imaging, however is slow in comparison to intensity imaging. Gil (7:395) developed a method of combining range and intensity data to derive complete edge maps. Both intensity and range gradients are computed and combined to form a coherent edge representation (7:398-99). The methods employed utilize one set of data to compliment the other. For example, if a list of connected intensity edge map points is constructed and the same route traced on a range edge map, a combined output map can be constructed. Advantages are that spurious or noise edges may be eliminated if not supported in the range map, while missing edges may be reclaimed if discontinuities occur in the range edge map. Experimental results verify the method as a way of obtaining a better approximation of the true scene edges (13:155). Intensity images often have false edges due to local reflectance changes. Range images are independent of reflectance changes and do not support these noise edges, thus eliminating them from the output edge map. Multisensory approaches used to create edge enhanced images would increase the accuracy of the correlation and feature extraction methods.

V. Conclusion and Recommendations

Conclusion

This study was undertaken to extend basic research efforts in the area of autonomous target recognition using correlation techniques in the analysis as the discriminator. Simulated laser range images of a sophisticated tank model were created using a computer and assuming ideal input conditions. The resulting images were pre-processed using two enhancement techniques; gradient filtering (frequency emphasis) and phase-only filtering. The enhanced images were used to explore the effects of object rotation on target recognition. An array of decoys was analysed to determine the degree of sophistication required in a decoy to fool the sensor. The reference tank image itself was analysed for its prominent features and subsequent applications in the area of feature extraction methods for target recognition.

Simple cross-correlation will not suffice as a target recognition technique given the possibility of rotated targets. This analysis demonstrated a maximum allowable 8 degrees of rotational variance in the scanned image if a correlation maximum of 0.70 is accepted. Under this condition, some method of multiple processing is required to pattern match up to 45 separate orientations of the reference image. Phase-only filtering proved as

rotationally dependent as the more conventional frequency filtering. It is believed that a method of sensing the primary axis of the correlation and using this information in further processing the correlation could improve its performance against rotated images.

Decoy analysis demonstrated that to fool the proposed sensor, at a threshold detection level correlation maximum of 0.70 the decoy would necessarily be a near duplicate of the tank in both scale and shape. In this analysis the two enhancement techniques produced different results. Phase-only filtering was found to be more effective in discriminating simple decoys from tanks than frequency filtering. A combination of these two techniques could prove highly effective due to the manner in which the results compliment each other. Also, the results suggest that the two types of enhancement techniques would be effective in different sensor roles; frequency filtering distinguishing between target classes, and phase-only emphasis used for discrimination within a class of targets.

The technique of feature extraction as an identification technique was examined briefly and it was concluded that a tank could be recognized by "looking" for its most prominent correlatable features, namely the gun tube, the side skirts, or a combination of the two.

Recommendations

There are several avenues open for further research in an extension of the research performed in this study. This research was aimed at real world scenarios and data. The next step is to work directly with actual range images, available from Eglin Air Force Base and compare actual with synthetic range images. This would add the next level of realism to this research and help validate its conclusions.

In most of today's literature on the subject of target recognition, correlations or similar forms of template matching are considered time consuming and too sensitive to changes in the input images. However, an established technology exists and need not be abandoned. This research suggested that information about an object's orientation could be obtained simply by examining its auto-correlation and cross-correlation with the reference image. While the computer cannot presently discern this information, an extension of this research worth pursuing is to modify the program to sense the major axis of the auto-correlation and automatically call up an appropriately rotated reference image for cross-correlation. The digital implementation of this technique is time consuming but utilizing the available optical technology to perform the correlations could make this approach realistic.

In order to reduce the computational time required and complexity of correlation, feature extraction is a viable alternative. Techniques similar to those presented in this research could be applied to the specific features identified as prominent and tested for recognition in a scene, or for the ability of the sensor to perform multiple image registration in a single range scene.

The potential of phase-only filtering as an image enhancing technique has not yet been fully explored. Further research into its effectiveness should be undertaken to completely understand its ability to discriminate targets and decoys.

Finally, this research should be extended into a multisensory approach to target identification. The potential exists to create a sensor with the ability to obtain data about its surroundings in the form of range, intensity and thermal imagery. A multisensory approach would use some combination of these or all the approaches to obtain the best image possible for target recognition and identification.

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VITA

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